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Valorized Food Processing By-Products in the EU: Finding the Balance between Safety, Nutrition, and Sustainability

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Abstract: Food businesses in the European Union are preparing for a carbon-neutral future by gradually transitioning to a circular way of operating. Building upon results from the EU REFRESH project, we consider the most valuable food processing by-streams in Europe and discuss potential food safety risks that must be considered while valorizing them for human consumption. These risks are weighed against the nutritional benefits offered by these products and their potential applications in food supply chains. Broadly, we examine whether it is possible for spent grains, cheese whey, fruit and vegetable scraps, meat processing waste, and oilseed cakes and meals to be safe, sustainable, and nutritionally valuable at the same time. The discussion highlights that valorizing by-products obtained from food processing operations is feasible on a large scale only if consumers deem it to be a safe and acceptable practice. Extracting valuable compounds from by-products and using them in the preparation of functional foods could be a way to gain consumer acceptance. Furthermore, we find that current EU food safety legislation does not sufficiently accommodate food processing by-products. A way to bridge this regulatory gap could be through the adoption of private food safety standards that have shown proclivity for sustainability-related issues in food supply chains. Finally, by proposing a decision tree, we show that it is indeed feasible for some food processing by-products to be valorized while ensuring sustainability, food safety, and nutritional relevance.

Keywords: food safety; functional foods; food waste; waste valorization; private standards

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1. Introduction

The European Commission's aspiration to move toward a circular economy is no secret. With the recent unveiling of the Green Deal, an ambitious plan to make Europe carbon neutral by 2050, it is clear that in the future, businesses will be expected to work with closed loops of resources to minimize waste and reduce the impact of their actions on the environment. The Farm to Fork strategy, a subset of the Green Deal, focuses on the food system and aims to employ the circular economy model to make food production more sustainable [1].

In the context of food supply chains, closing the loop would mean making better use of food waste, surplus, and by-products. It is estimated that around 88 million tons of food is wasted in Europe every year [2]. While saving at least a part of this amount might seem like an irreproachable goal, some of the most attractive solutions may make food less safe for consumers. As the innovative use of side streams and by-products becomes the new norm in a sustainable food system, changing food safety needs must be a core part of the development. The EU General Food Law does not define the concept of "safe food." Rather, it focuses on the negative concept of "unsafety" by stating in Article 14 (2) that food shall be deemed as unsafe if it is considered to be injurious to health or unfit for human

consumption. Furthermore, it does not make a distinction between products that are inherently unsafe and those that have been rendered unsafe by their specific condition [3]. This puts the burden of proof on food businesses and makes it a challenge for new or novel foods to be established as not unsafe.

Given the pervasive nature of food waste and the existence of different methods to measure it, there is no conclusive evidence on how much food is wasted at each stage of the food supply chain. Most studies focusing on measuring food waste in the EU agree that the largest share of food is wasted at the consumption stage. The processing stage is considered to be a close second. A report published by the European Commission compared six studies measuring food waste at different stages of the supply chain and found that the estimate for the processing stage (referred to as the manufacturing stage in the report) is between 12% and 41% [4]. While the amount of waste from households is higher than that from the processing stage, processing waste is less scattered and is more homogeneous in nature. This makes it a more attractive option for valorization.

In food waste management practices, the food waste hierarchy framework developed by Papargyropoulou et al. (2014) is widely applied [5]. This hierarchy makes preventing food waste a top priority, followed by reusing surplus food for human consumption. After this, the next priority is to convert food surplus to feed for animals that are part of the food chain. Up until this stage, food safety remains a central concern. The two last stages of the hierarchy include energy recovery and disposal. Once the waste has reached these stages, it is no longer part of the food supply chain and, therefore, food safety is no longer a concern. However, keeping food waste and surplus within the food supply chain is seen as the more sustainable option, considering environmental, economic, and social implications [5].

Known drivers of food waste at the processing stage include inadequate control systems, inefficient operations, poor use of equipment, spoilage caused by suboptimal handling and storing conditions, damage incurred during transportation, and cold chain inefficiencies [6]. REFRESH (2015–2019), a project funded by the European Commission mapped current knowledge on food waste valorization and developed tools to support decision-making regarding valorization pathways. Its predecessor, FUSIONS, was active between 2012 and 2016 and lay the groundwork for REFRESH by creating definitions and developing methodologies for measuring the extent of the problem. The two projects together have advanced the current understanding of Europe's food waste problem and set the course for future action. Topics such as legal and policy perspectives, life cycle analyses, economic aspects, business practices, and innovation have been covered by the projects. One of the outcomes of the REFRESH project was the creation of the FoodWasteExplorer—An open access database that provides information about biochemical composition of agri-food chain waste streams (available via www.foodwasteexplorer.eu. accessed on 13 April 2021). The database sources a majority of its information from other databases focused on animal feed. Therefore, in its current form, it is questionable whether data from FoodWasteExplorer can be used for valorizing food processing by-products for human consumption.

Next to these two EU projects, various review and meta-review articles have further improved current knowledge on the use of by-streams [7–11]. While food safety, sustainability, and nutrition are discussed to varying extents in literature, a critical reflection focusing on all three has never been published. Through this article, we hope to fill this gap. In line with Gilson and Goldberg's (2015) guidelines for conceptual papers, rather than collecting new data, we propose new, untested relationships among existing constructs found in literature [12]. In this paper, the untested relationship is the one shared by food safety, nutrition, and sustainability in the context of valorizing food processing by-products. Next to this, we employ Toulmin's "claims, grounds, and warrants" framework for constructing a sound argument [13,14]. The claim we make is that it is possible for valorized food processing by-products to be safe, sustainable, and nutritionally valuable at the same time. We then use arguments found in existing literature as grounds to support our claim.

As for warrants, which are underlying assumptions that link grounds to claims, we work with the presupposition that food safety, nutrition, and sustainability are equally important to the food industry in its pursuit to find ways to valorize food processing by-products.

For individual by-streams, the various articles cited in this paper as well as the FoodWasteExplorer database have already created comprehensive lists of hazards that could occur during the valorization process. Our aim, therefore, is not to repeat this exercise but to create new knowledge on the topic by weighing food safety risks against nutritional benefits and potential uses of these by-products.

2. Important By-Products in the EU

Similar to the estimates regarding waste at different stages of the supply chain, there is no conclusive evidence on the amount of waste generated by the various sub-sectors of the processing stage. However, recent work published by Caldeira et al. (2019) offers a well-founded estimate, calculated using the mass flow analysis concept [15]. The total food waste at the processing stage was found to be 30.6 million tons annually [15]. Figure 1 shows the estimated contribution of the top five sub-sectors at the processing stage.

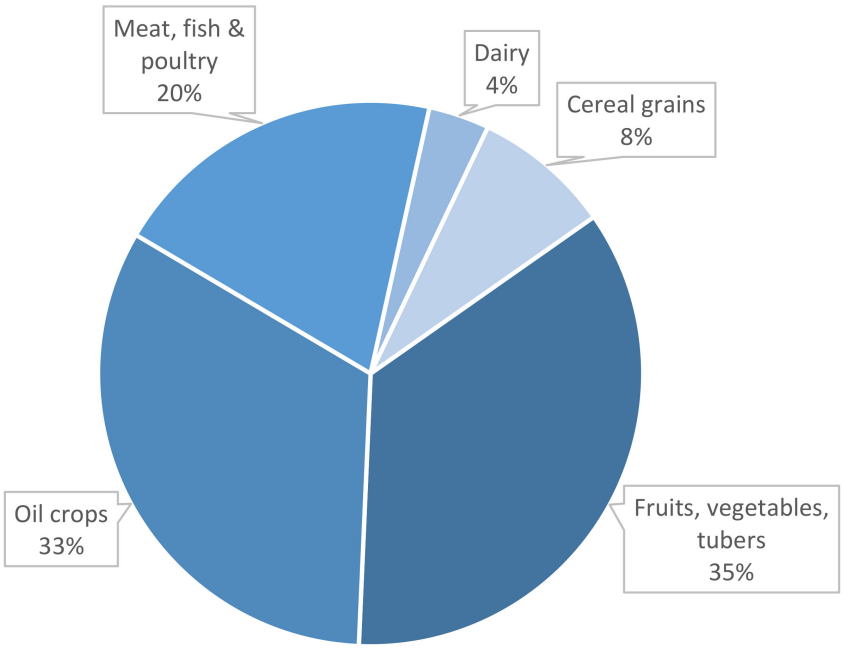


Figure 1. Food waste estimates per sub-sector at the processing stage [15].

Considering that food is wasted at the processing stage in significant quantities, it became important to identify which by-products should be given priority for valorization. This is a crucial step so as to enable the food industry, policy-makers, and legislators to set up infrastructure and resources focusing on valorizing specific by-products into new, valuable products. In 2016, REFRESH composed a list of 20 priority food waste streams. These were selected on the basis of their environmental impact and the volume generated [16]. All categories in Figure 1 find a place in the list, thus indicating that the sub-sectors with the highest volumes of waste are given priority in facilitating valorization. Below, some of the top contributors are discussed in the context of potential valorization pathways, food safety bottlenecks, and nutritional benefits.

2.1. Spent Grain

Spent grains, a by-product of ale, lager, and spirit production, is listed as one of the twenty priority streams due to the annual volume generated in the EU [16]. On average, 20 kg of spent grains remain behind for every hectoliter of these beverages produced [16]. It is estimated that 3.4 million tons of spent grains are produced within the

EU every year [17]. This by-product consists mostly of barley peel, pericarp, seeds, residual endosperm, and aleurone [18]. It is often referred to as brewer's spent grains or BSG.

BSG has a complex chemical composition, which makes it suitable for many valorization endeavors. However, the most prominent bottleneck in valorization is the high moisture content of BSG. At 80% moisture content, the average shelf life of this product is 7–10 days [18]. Together with its fermentable sugar contents, the high moisture makes BSG liable to rapid deterioration [17]. A study by Sodhi et al. (1985) found eight isolates of Aspergillus, Fusarium, Mucor, Penicillium, and Rhizopus in BSG stored in a gunnysack for 30 days [19].

To preserve BSG, various techniques can be used. Adding lactic acid, acetic acid, formic acid, or benzoic acid to moisture-rich BSG mixtures is known to effectively preserve quality and nutritional value [17]. Kuentzel and Sonnenberg (1997) found potassium sorbate to be effective as well. Spent grains can also be dried prior to storage [20]. This not only makes it less susceptible to microbial spoilage but also reduces the product volume, and as a result, decreases transport and storage costs [21]. Traditionally, BSG is dried using direct rotary-drum driers. However, this process is energy-intensive and is being replaced by more energy-efficient methods such as freeze-drying, oven drying, and freezing [22,23].

Next to microbiological risks, chemical risks must also be considered while valorizing BSG. A study published by Ekieslki and colleagues (2018) shows that chlormequat and mepiquat, two compounds commonly used as pesticides, can be formed while roasting grains during the brewing process [24]. Based on their work, it is possible that the spent grains obtained from darker malts may contain these toxic compounds in trace amounts.

Currently, BSG is used in food as well as feed applications. Incorporating BSG in the human diet can contribute to positive health effects [18]. Spent grains can be added to food products to increase their fiber and protein content [25]. The glutamine, non-cellulosic polysaccharides, and soluble dietary fibers present in BSG have been linked with accelerated intestinal transit, alleviation of both, diarrhea and constipation, decreased incidence of gallstones, as well as reduced cholesterol and postprandial glucose levels [23]. Due to the presence of biologically active compounds in BSG, food fortified with it is considered to be functional food [26]. Several studies involving pasta, bread, infant formula, and meat and fish products have shown that BSG can add significant nutritional value to foods [17,25–29]. For instance, Stojceska (2019) shows that by replacing 30% of regular flour with BSG during bread-making, the level of dietary fiber can increase up to five-fold [30]. This contributes toward consumers' recommended daily dietary fiber intake [30]. BSG can be used for technical applications related to food production such as the production of xylitol, lactic acid, and prebiotics [18]. It is also a source of phenolic compounds and can be used as a substrate for the growth of various microorganisms [18].

BSG is a low cost, nutritionally attractive material that is readily available in large quantities throughout the year [17]. Results from Lynch et al. (2016) indicate that developing efficient methods for its preservation and formulating legislation to govern the production and utilization process would substantially improve the safe use of BSG in various food application [17]. After focusing on ways to minimize waste, the beer brewing industry must work toward developing methods for complete recovery of by-products on a large scale [31]. Next to this, specific analytical methods for the characterization of functional compounds need should be developed [31]. This would aid in the valorization of not only BSG but also other valuable by-products such as hops and yeast. Lastly, the bioactivity, bioavailability, and toxicology of the functional components derived from BSG need to be assessed via in vitro and in vivo studies [31]. If this is achieved, we might see BSG being better utilized and kept within the food supply chain in the years to come.

2.2. Fruits, Vegetables, and Tubers

Pomace and peels of apples, oranges, tomatoes, potatoes, grapes, olives, and sugar beet find a prominent place in the REFRESH priority list. The disposal of these by-products is of lower consequence to the environment in comparison to some other waste streams,

but their leachate and methane emissions still present a risk [32,33]. Recovery solutions for fruit and vegetable waste streams are negatively impacted by the fact that they often contain large amounts of suspended solids and present high biochemical and chemical oxygen demand. As a result, recovery solutions and waste treatment become more expensive [10].

Pomace from apple processing and cider production is an important by-product for several European countries including the United Kingdom, France, Spain, Ireland, and Germany. Currently, the most widespread way to valorize this pomace is by converting it to animal feed. Given that apple pomace is a rich source of dietary fiber and antioxidants, various studies have considered ways to use it in food applications [34–36]. However, the safety of apple pomace for human consumption has not been comprehensively reviewed [37]. The incidence of the natural toxin amygdalin in apple seeds as well as the presence of plant protection products such as neonicotinoids and arsenic-based pesticides on apple skins is a source of concern while valorizing apple pomace for human consumption [37–40]. Patulin, a mycotoxin, also presents a food safety risk while valorizing apple pomace and skins [41]. However, the presence of this hazard does not render apple by-products unusable. Patulin can be controlled by employing a combination of control measures throughout the production process [42].

Similar to apple pomace, the safety of consuming tomato pomace has not been extensively studied. However, current literature mentions the possibility of adverse effects because of the mildly toxic glycoalkaloid, tomatine [43]. Next to this, allergic reactions to the various proteins present in the tomato and irritable bowel syndrome from consuming high amounts of seeds and skins have been reported in literature [44,45].

For South European countries like Spain, Italy, Greece, and Portugal, orange by-products such as peels, seeds, and membranes are an important waste stream. Several compounds like soluble sugars, fiber, lipids, organic acids, flavonoids, vitamins, and minerals found in these waste products can be of much value in food applications [46]. While conversion to animal feed remains the most popular valorization option for orange processing waste streams, several food applications have been successfully piloted in recent years [10]. However, utilizing orange peels in food applications without taking appropriate measures to remove pesticides might pose a food safety risk [47].

A number of studies have shown that food processing steps such as washing, boiling, and juicing can reduce the level of pesticide residues in food to a large extent [47–49]. However, some processing steps that involve dehydration lead to a concentration of pesticides [47,50,51]. Factors such as temperature and microbial activities can also cause pesticide residues to undergo transformation, leading to the contamination of food processing by-products with other chemicals [47,52,53].

Plant protection products are not the only food safety concern while valorizing fruit and vegetable processing by-streams. As in the case of apple pomace, other by-products can present risks in the form of toxins that are unique to them. When valorizing potato peels, for instance, glycoalkaloids found in the *Solanum* genera are a potential hazard [8,50]. While glycoalkaloids are present in various parts of the potato, they are more concentrated in peels. Therefore, while using peels in food products, this risk must be considered [51,52].

Another concern when utilizing fruit and vegetable processing by-products is microbial spoilage due to high moisture content. The food processing sector struggles with valorizing pomace and skins from tomato and grape processing operations because these by-products contain significant amounts of moisture [53,54]. Drying prior to storage can assure higher stability but it can also result in the concentration of pesticides. Furthermore, molds are also capable of producing mycotoxins at low levels of water activity [55].

Despite food safety concerns, fruit and vegetable by-products are an attractive resource for the food and nutraceutical industries. Epidemiological research indicates that regular consumption of fruits and vegetables is linked to a decreased risk for developing various diseases including cancer, cardiovascular disease, high blood pressure, diabetes, and Alzheimer's disease [56–58]. These health effects have been linked to the bioactive phytochemicals in fruits and vegetables [59]. The increasing consumer demand for such

compounds is often met through dietary supplements, functional foods, and nutraceuticals [59,60]. Fruit and vegetable by-products are rich sources of phytochemicals. As a result, the extraction of phenolic compounds, dietary fibers, and other bioactive compounds from these by-streams has been widely studied [61]. Compounds such as lycopene from tomato pomace [62,63] and various phenolic compounds from grape seed extract, apple peels, and orange peels [36,64–66] are examples of compounds that can be valuable for the food industry for their health effects.

Next to being a source of bioactive compounds, fruit pomace can also enhance the dietary fiber content of various food products. It can be included in cereal-based foods while retaining consumer acceptance, improving health benefits of the products, and also offering a way to upcycle valuable by-products that would have otherwise ended up as waste [67]. Quiles et al. (2018) showed that fruit pomace in its dried form can be used to enrich the dietary fiber content of various baked products like bread, cakes, muffins, cookies, biscuits, and extruded products [67].

Although this paper considers by-products from fruit, vegetable, and tuber processing as a single category, each by-stream presents unique challenges for valorization. Different parts such as stems, leaves, and skins of the same product can also present great diversity in the risks that must be considered prior to valorization. Much of the current knowledge on the topic focuses on the utilization of these by-streams for animal feed. If they are to be used for food applications, data regarding safety must be documented and current legislation on food safety must expand its scope to include these by-products. If this is accomplished, the amount of fruit, vegetable, and tuber by-products that leave the food supply chain could be substantially minimized.

2.3. Dairy

The dairy industry is a commercially important subsector of the European food industry. It is also the second largest contributor to food waste at the processing stage and generates large volumes of liquid waste. It is estimated that 9 million tons of cheese is produced within the EU per annum. This generates around 50 million m^3 of whey. Dairy processing by-products can contain proteins, fatty substances, salts, lactose, and cleaning chemicals [68]. The REFRESH list mentions whey, the protein-rich by-product of the cheesemaking process, as a priority waste stream.

Smithers (2008) points out that whey and its disposal have always been a source of nuisance for cheesemakers and casein manufacturers [69]. Throughout the sector's history, dairy companies have been on the lookout for the most economically attractive way to dispose of their whey. Some previously used disposal techniques include spraying the whey onto fields or discharging it into bodies of water or municipal sewage systems. These methods, however, have had severe environmental repercussions. The study notes that the biochemical oxygen demand of whey is estimated to be nearly 175 times higher than standard sewage effluent. This has led regulatory authorities to restrict the disposal of untreated whey. As a result, dairy companies are left with the obligation to find innovative ways either to dispose of or use their whey.

The contamination concerns regarding whey are closely related to those of milk and other milk products. Microbiological hazards are the biggest cause of concern for the dairy industry, followed by chemical and physical hazards [70]. Listeria monocytogenes, Staphylococcus aureus, Salmonella, and human pathogenic Escherichia coli have been identified as the most important microbiological hazards in dairy products [70]. Next to this, chemical hazards are known to end up in milk mainly due to ingestion or production of unwanted compounds by the cow [71]. Contaminated feed, grazing on contaminated soil, administration of veterinary medicines, and fraud are some key causes for concern [71]. Aflatoxin M1, environmental contaminants like dioxin and dioxin-like compounds, and veterinary drugs are the most concerning chemical hazards for the dairy industry. Metal and plastic particles are considered to be important physical hazards [71]. Literature on the safety of dairy products focuses mainly on milk or other commercially important products

like cheese and butter. Literature about safety concerns specific to whey is not widely available.

As with other by-products of food processing, conversion to animal feed remains an important valorization option for whey. However, the increasing interest in finding sustainable ways to meet the protein needs of a growing population has led researchers to take a keen interest in valorizing whey for direct human consumption [72]. Some long-standing valorization options include the production of beverages such as the Swiss drink Rivella and the Italian soft cheese ricotta. In the United States, cheese whey falls under the category of "generally recognized as safe." FDA regulations state, "GRAS is the self-determination of safety and regulatory compliance in an otherwise stringently regulated venue" [73].

With the overall trend to replace animal-source foods with plant-source ones, it is debatable whether investing resources to develop new ways to utilize dairy by-products aligns with the agenda to make food production more sustainable. Nevertheless, dairy is currently an important source of dietary protein which is a vital component of the human diet [74,75]. Given the commercially important position held by the dairy industry, the wide-spread consumption of dairy products, and the demand for protein-rich foods to feed the growing population, it is unlikely that dairy production will cease to exist in the near future.

It has been established that exercising individuals and athletes need more dietary protein than their sedentary counterparts [76]. This demand is often met through high quality supplemental protein sources like whey and casein protein [76]. Developing products from valorized whey with athletes as target consumers may therefore be beneficial. A meta-analysis focusing on the efficacy and safety of whey protein found that no relevant data on the safety of the product was reported in any of the included studies [77]. However, the same paper found that no side effects were reported either [77].

A recent study by Yadav et al., (2015) suggests that using whey as a substrate to create bioprotein might be an interesting way to keep whey within the food supply chain. Bioprotein is a heat-inactivated bacterial single-cell protein that can be used in both food and feed applications. However, the study also warns that contamination with carcinogenic components, metallic components, and mycotoxins is a possibility [78]. In 2018, "whey basic protein isolates" was approved as a novel food product in the EU for use in infant formula, meal replacement beverages, dietary foods for special medical purposes, and food supplements [79].

Identifying ways to valorize whey can help improve food security, keep valuable dietary proteins within the food supply chain, prevent environmental damage caused by whey disposal, and help the dairy industry become more circular. As per Smithers (2008), advancement in novel separation methods such as vibratory shear enhanced processing, chromatographic technology, high power ultrasound, ion exclusion, and molecular recognition-based isolation techniques will offer the dairy industry new opportunities to safely valorize whey for human consumption.

2.4. Meat and Other Animal Products

Globally, the demand for meat has been rising directly in proportion to consumers' increasing purchasing power. At the same time, interest in organ meats and non-prime cuts has been falling dramatically. As a result, the meat industry is left with large quantities of slaughterhouse by-products [10]. Stuck with 20% of the waste generated at the processing stage, the meat processing and allied sectors seem to be faced with a difficult conundrum as the food industry inches toward a more sustainable future. The REFRESH list mentions hair, feathers, hooves, feet, organ meat, proteinaceous matter, and eggshells as priority by-products [16].

Keeping meat processing by-products within the food supply chain is more challenging than valorizing by-products from other sectors of the food industry. Following the bovine spongiform encephalopathy (BSE) crisis, the handling of slaughterhouse waste is

very strictly regulated in the European Union. Organ meats such as brain, nerves attached to the brain, spinal cord, and bone marrow are classified as high risk because they may contain prions that can spread BSE and other neurodegenerative disorders [80]. Additionally, heavy metals like lead and cadmium are more likely to be found in higher concentrations in organ meat [81,82]. A study by Colles et al. (2020) indicated that the Flemish population's consumption of organ meat is likely to play a role in the increased perfluorinated compounds in their blood levels [82]. Perfluorinated compounds are degradation-resistant molecules that are made up of carbon chains bound by fluorine atoms. Exposure to them has been associated with adverse health effects.

Under the stringent requirements of Regulations (EC) No 999/2001 and No 853/2004, the meat industry is left with fewer options to utilize waste products. Council Directive 75/442/EEC classifies animal by-products in categories 1, 2, and 3 depending on the risk they pose. Only by-products classified as "Category 3" are considered safe for valorization for food and feed purposes. While staying in line with regulations, some valorization pathways to keep meat processing by-products in the food supply chain include production of processed foods such as sausages, use in specific animal feeds, and export of organ meats to countries that traditionally consume them.

Some functional ingredients can be derived from meat processing by-products as well. Bioactive peptides from these by-products offer various health-promoting properties. Hypocholesterolemic, antioxidant and antithrombotic peptides have been found to modulate the cardiovascular system [83]. Mineral binding peptides are known to act in gastrointestinal systems and immunomodulatory peptides in immune systems [83]. Results from Ryder et al. (2016) have shown that bioactive peptides extracted from blood and collagen could play a role in the production of health-promoting products [84].

Next to this, meat processing by-products can also offer compounds that have technological applications in the food industry [83]. For instance, immunoglobulins, serum albumin, and fibrinogen are used for their gelation and emulsification properties. Plasma proteins can be used for protein enrichment [85] and foaming [86]. White blood cells from sheep have been found to aid antimicrobial activity against S. aureus, E. coli, and P. aeruginosa [87]. The combination of enzymes thrombin and fibrinogen, registered under the trademark Fibrimex®, is used for binding meat pieces and for increasing the hardness and springiness of meat products [83]. Gelatin, obtained from the hydrolysis of collagen, is widely used in the food industry for its gel-forming ability. It is also used as a clarifying agent, stabilizer, and protective coating material [7,9]. Protein hydrolysates are used as flavoring agents as well [83].

Considering that meat processing by-products have shown great nutritional and economic potential, discarding them is no longer practical [88]. Valorizing them for direct use in human food may be riddled with food safety challenges but they can add value in the form of functional ingredients. Next to human and animal food applications, animal processing by-products can be safely valorized through use in the production of cosmetics, chemicals, leather, biodiesel, among others [88].

2.5. Oil Seed Cakes and Meals

Soybean, rapeseed, and sunflower are the three most widely processed oil seeds in the EU [89]. After oil is extracted from seeds, the main by-products left behind are oil cake and meal. It is estimated that 32 million tons of these by-products are produced in the EU on an annual basis [89]. Given these large volumes, both by-products find a place in the REFRESH list.

Edible oil cakes are nutritionally valuable and can be used to supplement human diets through addition in bakery products, infant foods, and multipurpose supplements [90]. Depending on the raw material and processing conditions, they can contain between 45 and 65% protein [91–94]. As per the studies published by Arrutia (2020) and Arntfield (2018), using them as functional protein flours is relatively straightforward and highly sustainable [91,95]. However, they are not widely used in food applications because

they contain antinutritive compounds like phytic acid and polyphenols. Being a large and diverse group of compounds, polyphenols can be both, nutritionally valuable and detrimental. In the case of oilseed by-products, they form insoluble complexes with proteins and reduce bioavailability [96,97]. However, the polyphenol content in oil cakes and meals can be reduced by aqueous ethanol extraction which increases protein availability and improves flavors [94].

Next to direct use in food products, oilseed cakes and meals can be retained in the food supply chain by using them as substrates for the production of bioactive compounds, enzymes, vitamins, pigments, flavors, and amino acids [90,92]. Oil cakes and meals contain phenolic acids, flavonoids and lignans in free, esterified or condensed forms [90]. These compounds help in reducing oxidative stress and can therefore help in the prevention of various types of cancers [90]. They can be extracted by using solvents, high pressure, microwave, and supercritical fluid [90]. Cakes and meals also act as excellent substrates for growing mushrooms [94,96,98]. Soybean oil cake was found to be especially suitable for this purpose in a study conducted by Krupodorova, et al. (2015) [98].

The safety of consuming oilseed cakes and meals has not been extensively studied yet. Oilseeds contain chemical compounds that aid in their growth and defense against insects and microorganisms. These compounds often end up in the by-products and can result in bottlenecks during valorization [91]. While most of them present antinutritional properties, allergenicity remains a cause for concern for soybean and rapeseed by-products [91].

Although not extensive, there has been some research on the safety of using oilseed by-products as animal feed. Mycotoxins have been known to enter the human food chain through the use of contaminated oil cakes and meals in animal feed [99]. Oil cakes and meals can get contaminated by toxigenic fungi during storage. Some pathogenic fungal strains that have been found belong to Aspergillus, Fusarium, Monascus, and Penicillium [99]. These strains are all capable of producing mycotoxins such as aflatoxin B1, alternariol, fumonisin B1, ochratoxin A, T-toxin, and zearalenone [99,100]. Next to contamination during storage, presence of fungi in the raw material can also lead to the formation of mycotoxins [99,101]. Threat from mycotoxins in oilseeds and processing by-products are often not taken into consideration in food safety because the refining process which takes place at a high temperature (240 °C for 6 h.) often destroys the fungal spores. Therefore, the oil obtained at the end of the process is free from fungi [99].

Like spent grains, oil cakes and meals are low-cost and nutritionally rich materials that are available in large quantities throughout the year. However, their antinutritional properties and tendency to get contaminated by fungi prevents these by-products from being directly utilized in food production. If oilseed cakes and meals are to be used widely for human consumption, their mycotoxin contamination needs to be further investigated. Methods to efficiently remove antinutritional properties without damaging the flavor profile and desirable physico-chemical properties must also be developed. In the meanwhile, these products can be used in food application indirectly through use as a substrate and through the extraction of beneficial compounds.

3. Discussion

3.1. Valorization for Animal Feed Versus Human Consumption

According to the food waste hierarchy, utilizing food and its by-products for human consumption takes precedence over conversion to animal feed [5]. In reality, this is not always feasible. Converting by-streams to animal feed is an attractive option because the safety and quality requirements for animal feed are often lower than those for human food. However, using the animal feed chain as a route to dispose of degraded or contaminated foodstuffs can have far-reaching consequences [102]. For instance, Riet-Correa et al. (2013) highlight how feeding visibly moldy potatoes and maize that have been declared unfit for human consumption to ruminants can lead to mycotoxicosis outbreaks [103]. Mycotoxins are hard to eradicate and once they enter the food chain via meat and dairy products, they

linger in it. Additionally, climate change is likely to present new challenges to controlling the proliferation of mycotoxin-producing fungi in Europe in the near future [104].

Other chemical, biological, and physical hazards are also a source of concern while valorizing food waste as feed. Most of these hazards are present in the food chain as well but proximity to consumers ensures higher accountability. Avenues to pivot by-streams that are currently used for animal feed to human consumption exist but must go through rigorous risk assessment before such products are made available to consumers. However, until then, conversion to animal feed will continue to be an important means to keep food processing by-streams within the food chain. The role of EU feed hygiene legislation, specifically Regulation (EC) No 183/2005, is crucial in ensuring that feed placed on the market is of an appropriate quality, is traceable, and is safe for animals and, by extension, humans.

3.2. Consumer Perspective

Despite the food industry's continued effort to move from a linear way of operating to a circular one, valorizing by-products from waste streams on a large scale is possible only if consumers deem it a safe and acceptable practice. While European consumers are increasingly inclined toward more sustainable diets, food safety remains an important concern in the post-BSE era. Although the food supply is likely to be safer than ever before, food safety is the main concern for one in five European consumers when purchasing food [105].

In recent years, consumer willingness to move toward a more sustainable food system has been studied quite extensively [106–109]. However, comprehensive studies focusing on willingness to consume products that include components derived from valorized food by-streams have been few. One study conducted as part of REFRESH looked into consumer perception of valorized food by-products and presented some preliminary findings on the topic [110]. Results from the study show that while consumers are comfortable with the idea of reducing food waste via familiar methods such as gleaning, valorization of processing by-products is perceived as less safe and trustworthy.

The same study indicated that consumers who feel a lack of connection with food producers, policy-makers, and legislators also tend to have a lack of trust in the safety of food products made from valorized surplus and by-products. Additionally, results from the study indicate that sociodemographic characteristics may impact consumer willingness to purchase valorized foods. Women were found to be less likely to purchase food made using valorized by-products than men because women were more risk averse regarding food safety. Furthermore, older participants were found to be more accepting of valorized food, possibly because of richer life experiences in the context of food production and processing. The authors consider this an indication that time will play an important role in the adoption of novel valorization methods.

Another study that examined the willingness of consumers to buy biscuits containing upcycled defatted sunflower oilcake flour concluded that information about nutritional and environmental benefits of these new foods play an important role in shaping consumer attitude [111]. Indicating the health and environmental benefits of such products through labels could improve their chances of succeeding in the market [112].

Using ingredients derived from by-products of food processing in functional foods and nutraceuticals could be another path to successful valorization. Several factors including higher consumer interest in the relationship between diet and health, increasing life expectancy, and the surge in healthcare cost drive the health food industry today [113]. The European nutraceutical market was valued at $6.4 billion in 2013 and was set to grow at an annual rate of 7.2% between 2013 and 2018 [113].

However, it is also known that European consumers are more critical of new products and technologies compared to their counterparts in other developed countries such as the United States [113]. Siró et al. (2008) hypothesize that Europeans' acceptance of functional foods is less unconditional and better thought-out as compared to consumers

in the US [113]. Van Trijp (2009) highlights that the European market for functional food is characterized by large regional differences when it comes to the use and acceptance of these foods; with Central and Northern European countries showing higher interest than Mediterranean countries [114]. Bigliardi and Galati (2013) indicate that several researchers in the field agree that functional foods have a generally positive image among consumers in Europe [115]. Therefore, it can be expected that European consumers that have previously shown interest in sustainably produced foods and foods that offer health benefits might be accepting of functional foods derived from food processing by-streams.

3.3. Legal Perspective

When by-products are used for food applications, businesses are required to follow the same safety standards that are applicable to regular foodstuffs. However, current food safety legislation does not sufficiently accommodate food processing by-products. For instance, Commission Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs, does not cover by-products like pomace, peels, skins, spent grains, whey, or oilseed cakes, and meals. As a result, contaminants unique to these by-products are overlooked. When considering Commission Regulation (EC) No. 2073/2005 on microbiological criteria for foodstuffs, a similar observation can be made, with the exception of whey and certain animal by-products. Commission Regulation (EU) 2018/62 that lists foodstuffs to which maximum residue levels for pesticides apply does not mention by-products either. As such, food processing by-products currently do not find a place in any lists or annexes of the EU legislation defining safety criteria.

A way to bridge this gap could be through the adoption of private food safety standards that accommodate the specific requirements of food processing by-products. It is known that actors in the food supply chain often work with private food safety standards as a way to cope with regulatory uncertainty [116,117]. Other characteristics of these standards such as their proclivity for sustainability-related issues and their tendency to pre-empt the future adoption of public regulations might prove them to be a useful tool for food businesses that wish to valorize their by-products [117]. This falls in line with REFRESH's recommendation to use voluntary agreements between actors in the food supply chain to tackle food waste. The advantage that private standards might have over voluntary agreements is that private standards are already widely used by the industry. Private food safety standards stand the chance to attract several businesses looking to make their operations more circular if they include risk assessments and safety criteria for by-products. If such standards become widely accepted among food businesses, it could impel legislators to expand the scope of current food safety legislation to include food processing by-products. This in turn would offer a safety net to food businesses looking to move towards a more circular way of operating.

4. Research Implications

All by-products discussed in this paper are unique in their composition and therefore present a diverse range of challenges for food businesses that wish to valorize them. While there is no universal formula to determine whether safety, sustainability, and nutritional relevance can be ensured when valorizing a by-product, it is possible to consider each by-product on a case-by-case basis. Based on the findings and deliberations discussed in this paper, we propose a decision tree. As shown in Figure 2, this decision tree can assist practitioners and businesses in deciding whether a food processing by-product should be valorized and retained in the food supply chain. The decision tree assumes that sustainability, safety, and nutritional quality are equally important in the valorization endeavor.

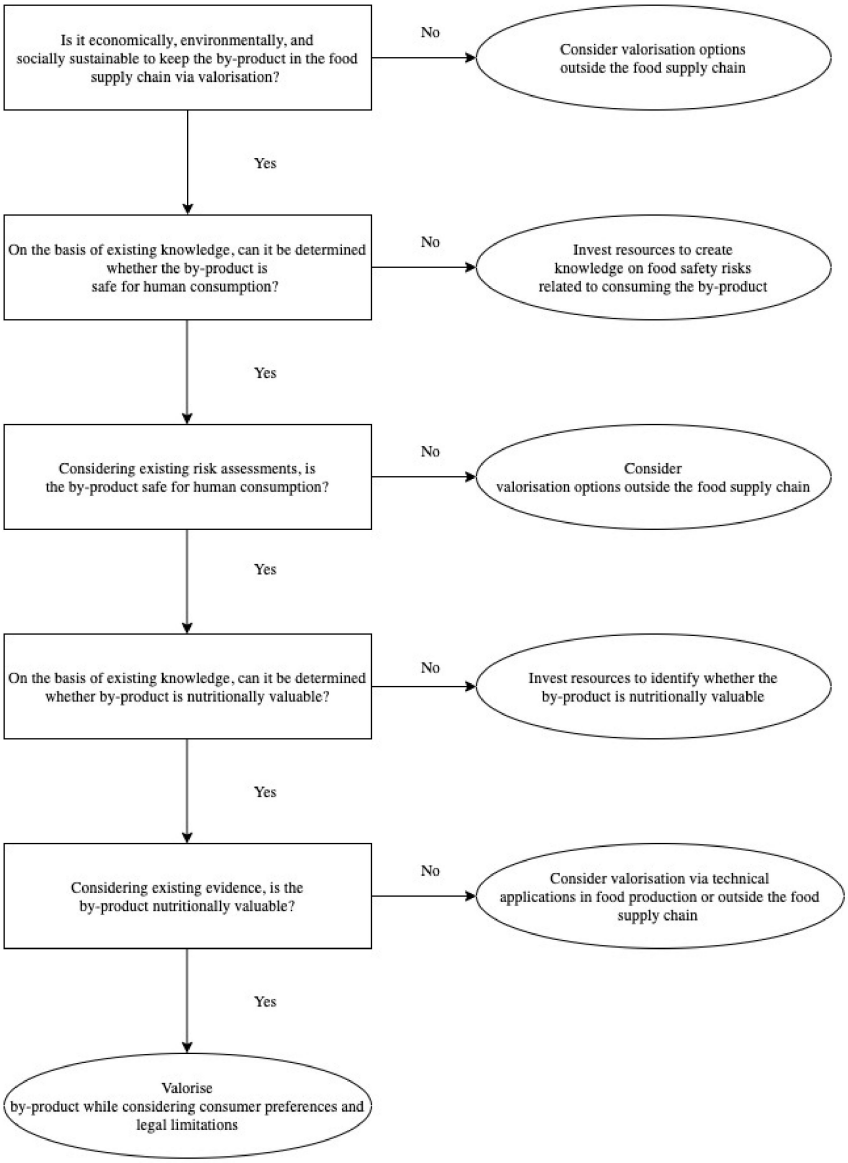


Figure 2. Decision tree supporting sustainable, safe, and nutritionally relevant valorization of food processing by-products.

The first step of the process requires businesses to identify whether it is sustainable to valorize the by-product. In line with the definition proposed by the United Nations Brundtland Commission in 1987, we consider sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their own needs" [118].

Before considering next steps, businesses must identify whether valorizing the by-product in question is an operation that can be carried out in the long term and whether its environmental, economic, and social outcomes are favorable. Depending on the context, various impact assessment models can be employed to identify whether valorizing the product is sustainable or not.

Next, it is critical to examine whether the by-product, after further processing, is safe for human consumption. If this information is not existent, businesses must invest resources to create new knowledge on the topic. Lastly, valorizing by-products and turning them into new food is justifiable only if they can add value to the human diet and do not negatively impact consumer health. It is important to note that decisions informed by this diagram

must be considered in the context of several external variables specific to the by-product in question.

5. Conclusions

By analyzing the existing knowledge on the topic through a conceptual lens, we suggest that it is possible to valorize food processing by-products while ensuring safety, high nutritional quality, and sustainability. Although well embedded in literature, it is important to further build upon the ideas discussed in this paper through empirical research. One way to do this could be by examining how food businesses practically experience the various bottlenecks mentioned in this paper and whether proposed solutions are practically feasible.

Despite this paper viewing food waste valorization through a European lens, its results and discussion can be extrapolated to the global context. The EAT–Lancet Commission's report on food in the Anthropocene indicates that significant reduction in the amount of food lost and wasted throughout the food supply chain is essential if the global food system is to stay within its safe operating space [119]. Innovative technological solutions and supporting public policies have a critical role to play in achieving a reduction in food loss and waste [119]. This philosophy is in line with the United Nations' Sustainable Development Goals, especially goal 12 focusing on responsible consumption and production.

In aspiring to decrease food waste while meeting stringent food safety requirements, the food industry must tread a tightrope. Achieving food production operations that are both sustainable and safe will require constant work to educate both consumers and food entrepreneurs [120]. It is also of vital importance for regulatory authorities, policy-makers, and legislators to be open to new ideas and to react quickly to new developments. While working with closed loops of resources in the food industry may present several obstacles, valorizing food processing by-products can offer improved food security, new sources of sustainable dietary proteins, and health-improving bioactive compounds.

In the EU, a fundamental requirement for putting food on the market is that it should be fit for human consumption and compliant with all food safety requirements. While the end goals of by-product valorization and ensuring food safety might not seem congruent, finding a middle ground is key to the success of any valorization endeavor. Private food safety standards willing to accommodate the special needs of such products could be key to achieving this middle ground. Keeping the food supply safe is an ongoing and dynamic undertaking. Being prepared to adapt to the demands of the changing times is the only way to make sure that the future of the food system is both safe and sustainable.

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References

1. European Commission. *Farm to Fork Strategy—For a Fair, Healthy and Environmentally-Friendly Food System*; European Commission: Brussels, Belgium, 2020.
2. Stenmarck, Å.; Jensen, C.; Quested, T.; Moates, G.; Buksti, M.; Cseh, B.; Juul, S.; Parry, A.; Politano, A.; Redlingshofer, B.; et al. *Estimates of European Food Waste Levels*; IVL Swedish Environmental Research Institute: 2016. Available online: https://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf (accessed on 13 April 2021).
3. Van der Meulen, B.M.J.; Szajkowska, A. The General Food Law: General provisions of food law. In *EU Food Law Handbook*; Wageningen Academic Publishers: Wageningen, The Netherlands, 2014; pp. 229–259. ISBN 978-90-8686-246-7.
4. Caldeira, C.; Corrado, S.; Sala, S. *JRC Technical Report—Food Waste Accounting Methodologies, Challenges and Opportunities*; Publications Office of the European Union: Luxembourg, 2017.
5. Papargyropoulou, E.; Lozano, R.; Steinberger, J.K.; Wright, N.; Ujang, Z. bin The Food Waste Hierarchy as a Framework for the Management of Food Surplus and Food Waste. *J. Clean. Prod.* **2014**, *76*, 106–115. [CrossRef]
6. Canali, M.; Amani, P.; Aramyan, L.; Gheoldus, M.; Moates, G.; Östergren, K.; Silvennoinen, K.; Waldron, K.; Vittuari, M. Food Waste Drivers in Europe, from Identification to Possible Interventions. *Sustainability* **2017**, *9*, 37. [CrossRef]
7. Djagny, K.B.; Wang, Z.; Xu, S. Gelatin: A Valuable Protein for Food and Pharmaceutical Industries: Review. *Crit. Rev. Food Sci. Nutr.* **2001**, *41*, 481–492. [CrossRef]
8. Gebrechristos, H.Y.; Chen, W. Utilization of Potato Peel as Eco-Friendly Products: A Review. *Food Sci. Nutr.* **2018**, *6*, 1352–1356. [CrossRef] [PubMed]
9. Gómez-Guillén, M.C.; Giménez, B.; López-Caballero, M.E.; Montero, M.P. Functional and Bioactive Properties of Collagen and Gelatin from Alternative Sources: A Review. *Food Hydrocoll.* **2011**, *25*, 1813–1827. [CrossRef]
10. Mirabella, N.; Castellani, V.; Sala, S. Current Options for the Valorization of Food Manufacturing Waste: A Review. *J. Clean. Prod.* **2014**, *65*, 28–41. [CrossRef]
11. Sagar, N.A.; Pareek, S.; Sharma, S.; Yahia, E.M.; Lobo, M.G. Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. *Compr. Rev. Food Sci. Food Saf.* **2018**, *17*, 512–531. [CrossRef]
12. Gilson, L.L.; Goldberg, C.B. Editors' Comment: So, What Is a Conceptual Paper? *Group Organ. Manag.* **2015**, *40*, 127–130. [CrossRef]
13. Jaakkola, E. Designing Conceptual Articles: Four Approaches. *AMS Rev.* **2020**, *10*, 18–26. [CrossRef]
14. Toulmin, S.E. *The Uses of Argument*; Cambridge University Press: Cambridge, UK, 2003; ISBN 978-0-521-53483-3.
15. Caldeira, C.; De Laurentiis, V.; Corrado, S.; van Holsteijn, F.; Sala, S. Quantification of Food Waste per Product Group along the Food Supply Chain in the European Union: A Mass Flow Analysis. *Resour. Conserv. Recycl.* **2019**, *149*, 479–488. [CrossRef]
16. Moates, G.; Sweet, N.; Bygrave, K.; Waldron, K. *Top 20 Food Waste Streams*. REFRESH. 2016. Available online: https://eu-refresh.org/sites/default/files/D6_9_Waste_Streams_Final.pdf (accessed on 13 April 2021).
17. Lynch, K.M.; Steffen, E.J.; Arendt, E.K. Brewers' Spent Grain: A Review with an Emphasis on Food and Health. *J. Inst. Brew.* **2016**, *122*, 553–568. [CrossRef]
18. Chetrariu, A.; Dabija, A. Brewer's Spent Grains: Possibilities of Valorization, a Review. *Appl. Sci.* **2020**, *10*, 5619. [CrossRef]
19. Sodhi, H.S.; Garcha, H.S.; Kiran, U. Screening of Mycoflora of Spent-up Brewers' Grains for Aflatoxin Production. *J. Res. Punjab. Agric. Univ.* **1985**, *22*, 6.
20. Kuentzel, U.; Sonnenberg, H. Conservation of pressed brewers grain with potassium sorbate. *Mon. Fuer Brauwiss. Ger.* **1997**, *50*, 175–181.
21. Santos, M.; Jiménez, J.J.; Bartolomé, B.; Gómez-Cordovés, C.; del Nozal, M.J. Variability of Brewer's Spent Grain within a Brewery. *Food Chem.* **2003**, *80*, 17–21. [CrossRef]
22. Bartolomé, B.; Santos, M.; Jiménez, J.J.; del Nozal, M.J.; Gómez-Cordovés, C. Pentoses and Hydroxycinnamic Acids in Brewer's Spent Grain. *J. Cereal Sci.* **2002**, *36*, 51–58. [CrossRef]
23. Mussatto, S.I. Brewer's Spent Grain: A Valuable Feedstock for Industrial Applications. *J. Sci. Food Agric.* **2014**, *94*, 1264–1275. [CrossRef]
24. Ekielski, A.; Mishra, P.K.; Żelaziński, T. Assessing the Influence of Roasting Process Parameters on Mepiquat and Chlormequat Formation in Dark Barley Malts. *Food Bioprocess Technol.* **2018**, *11*, 1177–1187. [CrossRef]
25. Stojceska, V.; Ainsworth, P. The Effect of Different Enzymes on the Quality of High-Fibre Enriched Brewer's Spent Grain Breads. *Food Chem.* **2008**, *110*, 865–872. [CrossRef]
26. McCarthy, A.L.; O'Callaghan, Y.C.; Piggott, C.O.; FitzGerald, R.J.; O'Brien, N.M. Brewers' Spent Grain; Bioactivity of Phenolic Component, Its Role in Animal Nutrition and Potential for Incorporation in Functional Foods: A Review. *Proc. Nutr. Soc.* **2013**, *72*, 117–125. [CrossRef]
27. Nazzaro, F.; Fratianni, F.; Ombra, M.N.; d'Acierno, A.; Coppola, R. Recovery of Biomolecules of High Benefit from Food Waste. *Curr. Opin. Food Sci.* **2018**, *22*, 43–54. [CrossRef]
28. Nocente, F.; Taddei, F.; Galassi, E.; Gazza, L. Upcycling of Brewers' Spent Grain by Production of Dry Pasta with Higher Nutritional Potential. *LWT* **2019**, *114*, 108421. [CrossRef]
29. Spinelli, S.; Conte, A.; Lecce, L.; Padalino, L.; Del Nobile, M.A. Supercritical Carbon Dioxide Extraction of Brewer's Spent Grain. *J. Supercrit. Fluids* **2016**, *107*, 69–74. [CrossRef]

30. Stojceska, V. Chapter 15—Brewer's Spent Grain From By-Product to Health: A Rich Source of Functional Ingredients. In *Flour and Breads and their Fortification in Health and Disease Prevention*, 2nd ed.; Preedy, V.R., Watson, R.R., Eds.; Academic Press: Cambridge, MA, USA, 2019; pp. 189–198. ISBN 978-0-12-814639-2.
31. Kao, T.H. Health Potential for Beer Brewing Byproducts. In *Biotechnology for Agro-Industrial Residues Utilisation*; Springer: Dordrecht, The Netherlands, 2018; pp. 313–326. ISBN 978-1-78923-208-0.
32. Misi, S.N.; Forster, C.F. Semi-Continuous Anaerobic Co-Digestion of Agro-Wastes. *Environ. Technol.* **2002**, *23*, 445–451. [CrossRef]
33. Sweet, N.; Bygrave, K.; Moates, G.; Waldron, K. *"Medium" List of Waste Streams Appropriate for Valorisation*. REFRESH. 2016. Available online: https://eu-refresh.org/sites/default/files/D6_1_Waste_Streams_Final.pdf (accessed on 13 April 2021).
34. Henríquez, C.; Speisky, H.; Chiffelle, I.; Valenzuela, T.; Araya, M.; Simpson, R.; Almonacid, S. Development of an Ingredient Containing Apple Peel, as a Source of Polyphenols and Dietary Fiber. *J. Food Sci.* **2010**, *75*, H172–H181. [CrossRef] [PubMed]
35. Huber, G.M.; Rupasinghe, H.P.V. Phenolic Profiles and Antioxidant Properties of Apple Skin Extracts. *J. Food Sci.* **2009**, *74*, C693–C700. [CrossRef] [PubMed]
36. Wolfe, K.L.; Liu, R.H. Apple Peels as a Value-Added Food Ingredient. *J. Agric. Food Chem.* **2003**, *51*, 1676–1683. [CrossRef] [PubMed]
37. Skinner, R.C.; Gigliotti, J.C.; Ku, K.-M.; Tou, J.C. A Comprehensive Analysis of the Composition, Health Benefits, and Safety of Apple Pomace. *Nutr. Rev.* **2018**, *76*, 893–909. [CrossRef]
38. Bolarinwa, I.F.; Orfila, C.; Morgan, M.R.A. Amygdalin Content of Seeds, Kernels and Food Products Commercially-Available in the UK. *Food Chem.* **2014**, *152*, 133–139. [CrossRef]
39. Lozowicka, B. Health Risk for Children and Adults Consuming Apples with Pesticide Residue. *Sci. Total Environ.* **2015**, *502*, 184–198. [CrossRef]
40. Opyd, P.M.; Jurgoński, A.; Juśkiewicz, J.; Milala, J.; Zduńczyk, Z.; Król, B. Nutritional and Health-Related Effects of a Diet Containing Apple Seed Meal in Rats: The Case of Amygdalin. *Nutrients* **2017**, *9*, 1091. [CrossRef] [PubMed]
41. Beretta, B.; Gaiaschi, A.; Galli, C.L.; Restani, P. Patulin in Apple-Based Foods: Occurrence and Safety Evaluation. *Food Addit. Contam.* **2000**, *17*, 399–406. [CrossRef] [PubMed]
42. Moake, M.M.; Padilla-Zakour, O.I.; Worobo, R.W. Comprehensive Review of Patulin Control Methods in Foods. *Compr. Rev. Food Sci. Food Saf.* **2005**, *4*, 8–21. [CrossRef]
43. Salehi, B.; Sharifi-Rad, R.; Sharopov, F.; Namiesnik, J.; Roointan, A.; Kamle, M.; Kumar, P.; Martins, N.; Sharifi-Rad, J. Beneficial Effects and Potential Risks of Tomato Consumption for Human Health: An Overview. *Nutrition* **2019**, *62*, 201–208. [CrossRef]
44. Laza, V. Tomatoes and Lycopene in the Athletes' Diet. *Palestrica Third Millenn. Civiliz. Sport* **2014**, *15*, 72–79.
45. Żukiewicz-Sobczak, W.A.; Wróblewska, P.; Adamczuk, P.; Kopczyński, P. Causes, Symptoms and Prevention of Food Allergy. *Adv. Dermatol. Allergol. Dermatol. Alergol.* **2013**, *30*, 113–116. [CrossRef]
46. Fernández-López, J.; Fernández-Ginés, J.M.; Aleson-Carbonell, L.; Sendra, E.; Sayas-Barberá, E.; Pérez-Alvarez, J.A. Application of Functional Citrus By-Products to Meat Products. *Trends Food Sci. Technol.* **2004**, *15*, 176–185. [CrossRef]
47. Li, Y.; Jiao, B.; Zhao, Q.; Wang, C.; Gong, Y.; Zhang, Y.; Chen, W. Effect of Commercial Processing on Pesticide Residues in Orange Products. *Eur. Food Res. Technol.* **2012**, *234*, 449–456. [CrossRef]
48. Burchat, C.S.; Ripley, B.D.; Leishman, P.D.; Ritcey, G.M.; Kakuda, Y.; Stephenson, G.R. The Distribution of Nine Pesticides between the Juice and Pulp of Carrots and Tomatoes after Home Processing. *Food Addit. Contam.* **1998**, *15*, 61–71. [CrossRef]
49. Randhawa, M.A.; Anjum, F.M.; Ahmed, A.; Randhawa, M.S. Field Incurred Chlorpyrifos and 3,5,6-Trichloro-2-Pyridinol Residues in Fresh and Processed Vegetables. *Food Chem.* **2007**, *103*, 1016–1023. [CrossRef]
50. Joshi, A.; Sethi, S.; Arora, B.; Azizi, A.F.; Thippeswamy, B. Potato Peel Composition and Utilization. In *Potato: Nutrition and Food Security*; Raigond, P., Singh, B., Dutt, S., Chakrabarti, S.K., Eds.; Springer: Singapore, 2020; pp. 229–245. ISBN 9789811576621.
51. Hossain, M.B.; Tiwari, B.K.; Gangopadhyay, N.; O'Donnell, C.P.; Brunton, N.P.; Rai, D.K. Ultrasonic Extraction of Steroidal Alkaloids from Potato Peel Waste. *Ultrason. Sonochem.* **2014**, *21*, 1470–1476. [CrossRef] [PubMed]
52. Sánchez Maldonado, A.F.; Mudge, E.; Gänzle, M.G.; Schieber, A. Extraction and Fractionation of Phenolic Acids and Glycoalkaloids from Potato Peels Using Acidified Water/Ethanol-Based Solvents. *Food Res. Int.* **2014**, *65*, 27–34. [CrossRef]
53. Al-Muhtaseb, A.H.; Al-Harahsheh, M.; Hararah, M.; Magee, T.R.A. Drying Characteristics and Quality Change of Unutilized-Protein Rich-Tomato Pomace with and without Osmotic Pre-Treatment. *Ind. Crops Prod.* **2010**, *31*, 171–177. [CrossRef]
54. García-Lomillo, J.; González-SanJosé, M.L. Applications of Wine Pomace in the Food Industry: Approaches and Functions. *Compr. Rev. Food Sci. Food Saf.* **2017**, *16*, 3–22. [CrossRef] [PubMed]
55. Romagnoli, B.; Menna, V.; Gruppioni, N.; Bergamini, C. Aflatoxins in Spices, Aromatic Herbs, Herb-Teas and Medicinal Plants Marketed in Italy. *Food Control* **2007**, *18*, 697–701. [CrossRef]
56. He, F.J.; Nowson, C.A.; Lucas, M.; MacGregor, G.A. Increased Consumption of Fruit and Vegetables Is Related to a Reduced Risk of Coronary Heart Disease: Meta-Analysis of Cohort Studies. *J. Hum. Hypertens.* **2007**, *21*, 717–728. [CrossRef]
57. Kromhout, D.; Spaaij, C.J.K.; de Goede, J.; Weggemans, R.M. The 2015 Dutch Food-Based Dietary Guidelines. *Eur. J. Clin. Nutr.* **2016**, *70*, 869–878. [CrossRef]
58. McCall Damian, O.; McGartland Claire, P.; McKinley Michelle, C.; Patterson Chris, C.; Sharpe, P.; McCance David, R.; Young Ian, S.; Woodside Jayne, V. Dietary Intake of Fruits and Vegetables Improves Microvascular Function in Hypertensive Subjects in a Dose-Dependent Manner. *Circulation* **2009**, *119*, 2153–2160. [CrossRef]

59. Liu, R.H. Health Benefits of Fruit and Vegetables Are from Additive and Synergistic Combinations of Phytochemicals. *Am. J. Clin. Nutr.* **2003**, *78*, 517S–520S. [CrossRef]
60. Timbo, B.B.; Ross, M.P.; McCarthy, P.V.; Lin, C.-T.J. Dietary Supplements in a National Survey: Prevalence of Use and Reports of Adverse Events. *J. Am. Diet. Assoc.* **2006**, *106*, 1966–1974. [CrossRef]
61. Galanakis, C.M. Recovery of High Added-Value Components from Food Wastes: Conventional, Emerging Technologies and Commercialized Applications. *Trends Food Sci. Technol.* **2012**, *26*, 68–87. [CrossRef]
62. Allison, B.J.; Simmons, C.W. Valorization of Tomato Pomace by Sequential Lycopene Extraction and Anaerobic Digestion. *Biomass Bioenergy* **2017**, *105*, 331–341. [CrossRef]
63. Van Steenwijk, H.P.; Bast, A.; de Boer, A. The Role of Circulating Lycopene in Low-Grade Chronic Inflammation: A Systematic Review of the Literature. *Molecules* **2020**, *25*, 4378. [CrossRef] [PubMed]
64. Babbar, N.; Oberoi, H.S.; Sandhu, S.K. Therapeutic and Nutraceutical Potential of Bioactive Compounds Extracted from Fruit Residues. *Crit. Rev. Food Sci. Nutr.* **2015**, *55*, 319–337. [CrossRef] [PubMed]
65. Chen, Y.; Wen, J.; Deng, Z.; Pan, X.; Xie, X.; Peng, C. Effective Utilization of Food Wastes: Bioactivity of Grape Seed Extraction and Its Application in Food Industry. *J. Funct. Foods* **2020**, *73*, 104113. [CrossRef]
66. Weseler, A.R.; Bast, A. Masquelier's Grape Seed Extract: From Basic Flavonoid Research to a Well-Characterized Food Supplement with Health Benefits. *Nutr. J.* **2017**, *16*, 5. [CrossRef] [PubMed]
67. Quiles, A.; Campbell, G.M.; Struck, S.; Rohm, H.; Hernando, I. Fiber from Fruit Pomace: A Review of Applications in Cereal-Based Products. *Food Rev. Int.* **2018**, *34*, 162–181. [CrossRef]
68. Kosseva, M.R. Processing of Food Wastes. In *Advances in Food and Nutrition Research*; Academic Press: Cambridge, MA, USA, 2009; Volume 58, pp. 57–136.
69. Smithers, G.W. Whey and Whey Proteins—From 'Gutter-to-Gold. *Int. Dairy J.* **2008**, *18*, 695–704. [CrossRef]
70. Van Asselt, E.D.; van Fels-Klerx, H.J.; der Marvin, H.J.P.; van Veen, H.B.; de Groot, M.N. Overview of Food Safety Hazards in the European Dairy Supply Chain. *Compr. Rev. Food Sci. Food Saf.* **2017**, *16*, 59–75. [CrossRef]
71. Van Asselt, E.D.; Marvin, H.J.P.; Boon, P.E.; Swanenburg, M.; Zeilmaker, M.; Mengelers, M.J.B.; van der Fels-Klerx, H.J. Chemical and Physical Hazards in the Dairy Chain. 2016. Available online: https://edepot.wur.nl/447318 (accessed on 13 April 2021).
72. Prazeres, A.R.; Carvalho, F.; Rivas, J. Cheese Whey Management: A Review. *J. Environ. Manag.* **2012**, *110*, 48–68. [CrossRef]
73. Burdock, G.A.; Carabin, I.G. Generally Recognized as Safe (GRAS): History and Description. *Toxicol. Lett.* **2004**, *150*, 3–18. [CrossRef]
74. De Boer, J.; Helms, M.; Aiking, H. Protein Consumption and Sustainability: Diet Diversity in EU-15. *Ecol. Econ.* **2006**, *59*, 267–274. [CrossRef]
75. Pedersen, A.N.; Kondrup, J.; Børsheim, E. Health Effects of Protein Intake in Healthy Adults: A Systematic Literature Review. *Food Nutr. Res.* **2013**. [CrossRef]
76. Campbell, B.; Kreider, R.B.; Ziegenfuss, T.; La Bounty, P.; Roberts, M.; Burke, D.; Landis, J.; Lopez, H.; Antonio, J. International Society of Sports Nutrition Position Stand: Protein and Exercise. *J. Int. Soc. Sports Nutr.* **2007**, *4*, 8. [CrossRef]
77. Lam, F.-C.; Bukhsh, A.; Rehman, H.; Waqas, M.K.; Shahid, N.; Khaliel, A.M.; Elhanish, A.; Karoud, M.; Telb, A.; Khan, T.M. Efficacy and Safety of Whey Protein Supplements on Vital Sign and Physical Performance Among Athletes: A Network Meta-Analysis. *Front. Pharmacol.* **2019**, *10*. [CrossRef]
78. Yadav, J.S.S.; Yan, S.; Pilli, S.; Kumar, L.; Tyagi, R.D.; Surampalli, R.Y. Cheese Whey: A Potential Resource to Transform into Bioprotein, Functional/Nutritional Proteins and Bioactive Peptides. *Biotechnol. Adv.* **2015**, *33*, 756–774. [CrossRef] [PubMed]
79. Turck, D.; Bresson, J.-L.; Burlingame, B.; Dean, T.; Fairweather-Tait, S.; Heinonen, M.; Hirsch-Ernst, K.I.; Mangelsdorf, I.; McArdle, H.J.; Naska, A.; et al. Safety of Whey Basic Protein Isolates as a Novel Food Pursuant to Regulation (EU) 2015/2283. *EFSA J.* **2018**, *16*, e05360. [CrossRef]
80. Glatzel, M.; Aguzzi, A. PrPC Expression in the Peripheral Nervous System Is a Determinant of Prion Neuroinvasion. *J. Gen. Virol.* **2000**, *81*, 2813–2821. [CrossRef] [PubMed]
81. Alao, B.; Falowo, A.; Chulayo, A.; Muchenje, V. The Potential of Animal By-Products in Food Systems: Production, Prospects and Challenges. *Sustainability* **2017**, *9*, 1089. [CrossRef]
82. Colles, A.; Bruckers, L.; Den Hond, E.; Govarts, E.; Morrens, B.; Schettgen, T.; Buekers, J.; Coertjens, D.; Nawrot, T.; Loots, I.; et al. Perfluorinated Substances in the Flemish Population (Belgium): Levels and Determinants of Variability in Exposure. *Chemosphere* **2020**, *242*, 125250. [CrossRef] [PubMed]
83. Toldrá, F.; Mora, L.; Reig, M. New Insights into Meat By-Product Utilization. *Meat Sci.* **2016**, *120*, 54–59. [CrossRef] [PubMed]
84. Ryder, K.; Bekhit, A.E.-D.; McConnell, M.; Carne, A. Towards Generation of Bioactive Peptides from Meat Industry Waste Proteins: Generation of Peptides Using Commercial Microbial Proteases. *Food Chem.* **2016**, *208*, 42–50. [CrossRef] [PubMed]
85. Yousif, A.M.; Cranston, P.; Deeth, H.C. Incorporation of Bovine Dry Blood Plasma into Biscuit Flour for the Production of Pasta. *LWT Food Sci. Technol.* **2003**, *36*, 295–302. [CrossRef]
86. Del Hoyo, P.; Rendueles, M.; Díaz, M. Effect of Processing on Functional Properties of Animal Blood Plasma. *Meat Sci.* **2008**, *78*, 522–528. [CrossRef]
87. Bah, C.S.; Bekhit, A.E.-D.A.; Carne, A.; McConnell, M.A. Composition and Biological Activities of Slaughterhouse Blood from Red Deer, Sheep, Pig and Cattle. *J. Sci. Food Agric.* **2016**, *96*, 79–89. [CrossRef]

88. Toldrá, F.; Aristoy, M.-C.; Mora, L.; Reig, M. Innovations in Value-Addition of Edible Meat by-Products. *Meat Sci.* **2012**, *92*, 290–296. [CrossRef]
89. FEDIOL Statistics. Available online: https://www.fediol.eu/web/2019/1011306087/list1187970188/f1.html (accessed on 26 March 2021).
90. Ancuța, P.; Sonia, A. Oil Press-Cakes and Meals Valorization through Circular Economy Approaches: A Review. *Appl. Sci.* **2020**, *10*, 7432. [CrossRef]
91. Arntfield, S.D. Proteins from oil-producing plants. In *Proteins in Food Processing (Second Edition)*; Yada, R.Y., Ed.; Woodhead Publishing Series in Food Science, Technology and Nutrition; Woodhead Publishing: Cambridge, UK, 2018; pp. 187–221. ISBN 978-0-08-100722-8.
92. Gupta, A.; Sharma, R.; Singh, B. Oilseed as Potential Functional Food Ingredient. 2019. Available online: https://www.researchgate.net/publication/337561630_Oilseed_as_potential_functional_food_Ingredient (accessed on 13 April 2021).
93. Kowalska, G.; Kowalski, R.; Hawlena, J.; Rowiński, R. Seeds of Oilseed Rape as an Alternative Source of Protein and Minerals. *J. Elem.* **2020**, *25*, 513–522. [CrossRef]
94. Schweiggert-Weisz, U.; Eisner, P.; Bader-Mittermaier, S.; Osen, R. Food Proteins from Plants and Fungi. *Curr. Opin. Food Sci.* **2020**, *32*, 156–162. [CrossRef]
95. Arrutia, F.; Binner, E.; Williams, P.; Waldron, K.W. Oilseeds beyond Oil: Press Cakes and Meals Supplying Global Protein Requirements. *Trends Food Sci. Technol.* **2020**, *100*, 88–102. [CrossRef]
96. Rozan, P.; Villaum, C.; Bau, H.M.; Schwertz, A.; Nicolas, J.P.; Méjean, L. Detoxication of Rapeseed Meal by Rhizopus Oligosporus Sp-T3: A First Step towards Rapeseed Protein Concentrate. *Int. J. Food Sci. Technol.* **1996**, *31*, 85–90. [CrossRef]
97. Roos, N.; Sørensen, J.C.; Sørensen, H.; Rasmussen, S.K.; Briend, A.; Yang, Z.; Huffman, S.L. Screening for Anti-Nutritional Compounds in Complementary Foods and Food Aid Products for Infants and Young Children. *Matern. Child. Nutr.* **2013**, *9*, 47–71. [CrossRef]
98. Krupodorova, T.; Barshteyn, V.Y. Alternative Substrates for Higher Mushrooms Mycelia Cultivation. *J. Biosci. Biotechnol.* **2015**, *4*, 339–347.
99. Bhat, R.; Reddy, K.R.N. Challenges and Issues Concerning Mycotoxins Contamination in Oil Seeds and Their Edible Oils: Updates from Last Decade. *Food Chem.* **2017**, *215*, 425–437. [CrossRef]
100. Garon, D.; Richard, E.; Sage, L.; Bouchart, V.; Pottier, D.; Lebailly, P. Mycoflora and Multimycotoxin Detection in Corn Silage: Experimental Study. *J. Agric. Food Chem.* **2006**, *54*, 3479–3484. [CrossRef]
101. Banu, N.; Muthumary, J.P. Mycobiota of Sunflower Seeds and Samples Collected from Vegetable Oil Refinery Located in Tamilnadu, India. *Mycol. Prog.* **2005**, *4*, 195–204. [CrossRef]
102. Thieme, O.; Makkar, H.P.S. Utilisation of Loss and Waste during the Food-Production Cycle as Livestock Feed. *Anim. Prod. Sci.* **2017**, *57*, 601–607. [CrossRef]
103. Riet-Correa, F.; Rivero, R.; Odriozola, E.; de Adrien, M.L.; Medeiros, R.M.T.; Schild, A.L. Mycotoxicoses of Ruminants and Horses. *J. Vet. Diagn. Investig.* **2013**, *25*, 692–708. [CrossRef]
104. Paterson, R.R.M.; Lima, N. How Will Climate Change Affect Mycotoxins in Food? *Food Res. Int.* **2010**, *43*, 1902–1914. [CrossRef]
105. European Food Safety Authority; European Commission. *2019 Eurobarometer on Food Safety in the EU*; European Commission: Brussels, Belgium, 2019.
106. Azzurra, A.; Massimiliano, A.; Angela, M. Measuring Sustainable Food Consumption: A Case Study on Organic Food. *Sustain. Prod. Consum.* **2019**, *17*, 95–107. [CrossRef]
107. Hartmann, C.; Siegrist, M. Consumer Perception and Behaviour Regarding Sustainable Protein Consumption: A Systematic Review. *Trends Food Sci. Technol.* **2017**, *61*, 11–25. [CrossRef]
108. Von Meyer-Höfer, M.; von der Wense, V.; Spiller, A. Characterising Convinced Sustainable Food Consumers. *Br. Food J.* **2015**, *117*, 1082–1104. [CrossRef]
109. Yang, Q.; Shen, Y.; Foster, T.; Hort, J. Measuring Consumer Emotional Response and Acceptance to Sustainable Food Products. *Food Res. Int.* **2020**, *131*, 108992. [CrossRef]
110. Djamel, R.; Jose Maria, G. *Valorisation of Food Surpluses and Side-Flows and Citizens' Understanding*. REFRESH. 2018. Available online: https://eu-refresh.org/valorisation-food-surpluses-and-side-flows-and-citizens%E2%80%99-understanding (accessed on 13 April 2021).
111. Asioli, D.; Grasso, S. Do Consumers Value Food Products Containing Upcycled Ingredients? The Effect of Nutritional and Environmental Information. *Food Qual. Prefer.* **2021**, *91*, 104194. [CrossRef]
112. Coderoni, S.; Perito, M.A. Sustainable Consumption in the Circular Economy. An Analysis of Consumers' Purchase Intentions for Waste-to-Value Food. *J. Clean. Prod.* **2020**, *252*, 119870. [CrossRef]
113. Siró, I.; Kápolna, E.; Kápolna, B.; Lugasi, A. Functional Food. Product Development, Marketing and Consumer Acceptance—A Review. *Appetite* **2008**, *51*, 456–467. [CrossRef]
114. Van Trijp, H.C.M. Consumer Understanding and Nutritional Communication: Key Issues in the Context of the New EU Legislation. *Eur. J. Nutr.* **2009**, *48*, 41–48. [CrossRef]
115. Bigliardi, B.; Galati, F. Innovation Trends in the Food Industry: The Case of Functional Foods. *Trends Food Sci. Technol.* **2013**, *31*, 118–129. [CrossRef]

116. Charlier, C.; Valceschini, E. Food Safety, Market Power and Private Standards: An Analysis of the Emerging Strategies of Food Operators. *Int. J. Food Syst. Dyn.* **2010**, *1*, 103–110. [CrossRef]
117. Rao, M.; Bast, A.; de Boer, A. European Private Food Safety Standards in Global Agri-Food Supply Chains: A Systematic Review. *Int. Food Agribus. Manag. Rev.* **2021**, in press. [CrossRef]
118. United Nations Academeic Impact Sustainability. Available online: https://academicimpact.un.org/content/sustainability (accessed on 1 April 2021).
119. Willett, W.; Rockström, J.; Loken, B.; Springmann, M.; Lang, T.; Vermeulen, S.; Garnett, T.; Tilman, D.; DeClerck, F.; Wood, A.; et al. Food in the Anthropocene: The EAT–Lancet Commission on Healthy Diets from Sustainable Food Systems. *Lancet* **2019**, *393*, 447–492. [CrossRef]
120. Kasza, G.; Szabó-Bódi, B.; Lakner, Z.; Izsó, T. Balancing the Desire to Decrease Food Waste with Requirements of Food Safety. *Trends Food Sci. Technol.* **2019**, *84*, 74–76. [CrossRef]