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Editorial

Food Waste Valorization

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Abstract: During the industrial processing of agricultural or animal products, large amounts of waste are produced. These wastes, generated in large amounts throughout the seasons of the year, can be considered the most abundant renewable resources on earth. Due to the large availability and richness in components of these raw materials, there is a great interest in their reuse, both from an economical and environmental point of view. This economical interest is based on the fact that a high quantity of such wastes could be used as low-cost raw materials for the production of new value-added compounds, with a further production cost reduction. The environmental concern is derived from their composition, especially the agro-industrial wastes that can contain potentially toxic compounds, which may cause deterioration of the environment when uncontrolled wastes are either burned, left on the soil to decay naturally, or buried underground. Moreover, these materials exhibit both high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) values and give rise to serious pollution problems if not properly discarded. Recycling and transformation of food wastes represent a great opportunity in supporting sustainable development by their conversion into value-added products through the fermentation process.

Keywords: waste management; biofuel production; circular economy; sustainability; single cell protein; fermentation; value-added product; food and feed production; yeast; probiotics

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1. Food Waste Valorization

Food waste is becoming a growing and important concern at both local and global levels [1,2]. According to the Food and Agriculture Organisation of the United Nations (FAO), one-third of all food production is lost or wasted globally, equivalent to 1.3 billion tons of food produced for human consumption wasted per year with an economic loss of EUR 800 billion [3]. About 44–47% is represented by fruit, vegetable, meat, and fish produced every year and wasted [4]. Because of the large availability and the composition of food waste, there is an increasing interest in their recycling and valorization.

Appropriate waste management is recognized as an essential prerequisite for sustainable development, contributing to the attainment of the global sustainability goals (SDGs 12 and 13). In this regard, Tsai et al. [5] reported an interesting study focused on the promotion policies and regulatory measures for the valorization of mandatory recyclable food waste from industrial sources in Taiwan, where the central governing agencies jointly promulgated some regulatory measures for promoting the production of bio-based products from the industrial food waste valorization such as animal feed, soil fertilizer, and bioenergy [5].

Additionally, food waste has a high potential due to its chemical composition, mainly represented by carbohydrate polymers such as starch, proteins, lipids, cellulose, and other microelements [6–9]. Due to this composition, it can be classified as a low-cost, high potency second-generation feedstock [1]. Recycling and bioconversion of food wastes represent a great opportunity in supporting sustainable development by their conversion, through a microbial fermentation process, into value-added products such as enzymes, feed and food additives, fertilizer, biofuels, animal feeds as well as other useful chemicals or products, food grade pigments, and single cell protein (SCP), enhancing food security and environmentally sustainable development [10–21].

2. Food Waste Valorization by Biofuel and Bioenergy Production

Due to its richness in moisture, carbohydrate polymers, and other constituents, food waste has been used as an excellent feedstock for the production of biofuel and bioenergy via microbial conversion [22,23]. The production of bioenergy from food waste would not only solve the environmental hazards resulting from the incineration of plants and sanitary landfill sites but would also mitigate the emissions of greenhouse gases while replacing the usage of fossil fuels with bioenergy [5].

Biomass such as rice husk, one of the most important crop residues around the world, can be converted by biochemical and thermochemical methods into useful products, as described by Tsai et al. [24]. Among the several methods applicable, pyrolysis is one of the most commonly used thermochemical conversion processes that involves the decomposition of biomass in the absence of air or oxygen at an elevated temperature [25]. The resulting biochar can be further used as solid fuel, carbon material, soil amendment, environmental adsorbent (biosorbent), functional catalyst, or feedstock for chemicals, depending on its final applications [26]. The study pointed out that rice husk-based biochar could be used as a material in environmental applications for water conservation, wastewater treatment, and soil amendment [24].

Pandit et al. [16] reviewed the bioenergy production using various types of agro-industrial wastewaters and agricultural residues utilizing the microbial fuel cell (MFC), also highlighting the techno-economics and lifecycle assessment of MFC, its commercialization, along with challenges. The use of different agricultural wastes and wastewater containing different industrial-by products for bioelectricity production in MFC seems to be a promising and alternative source of renewable energy generation. Moreover, it has been shown that different varieties of agricultural wastes and wastewater can be utilized using several different MFCs to enhance bioenergy production; thus, the conversion of agro-waste into bioenergy can be carried out by both biochemical and thermochemical MFC routes [16].

Another important issue concerning food waste biovalorization for bioethanol production is the substrate composition and the nutrients available for the microorganisms employed. It is well known that ethanol production is mainly dependent on glucose concentration (the theoretical alcohol yield is about 0.5 g of ethanol per g of glucose) and the yeast inoculums concentration, but nutrient supplementation is also an important parameter to take into consideration, since an adequate amount of specific nutrients, such as trace elements, vitamins, and nitrogen, often poor in agricultural waste, can significantly improve yeast viability and resistance to the medium, stimulating ethanol production performances [21,27]. Therefore, alcoholic fermentation is a complex biological process involving various operating factors, and the use of the classical "one factor at a time" approach for enhancing the final yield, could be time-consuming due to the large number of experiments to perform. In this regard, to implement an efficient fermentation process using industrial by-products, a predictive tool was investigated by Beigbeder et al. [17] to optimize the production of ethanol from non-treated sugar beet molasses by designing and developing a central composite design coupled with response surface methodology (CCD-RSM) statistical approach to investigate the effect of three fermentation process parameters (initial sugar, yeast, and nutrient concentrations) on ethanol productivity while considering several operating parameters such as ethanol yield and sugar utilization rate. Moreover, the second-order mathematical model obtained through the CCD-RSM was tested to evaluate its ability to make accurate predictions based on specific desired process outputs. The application of the CCDRSM statistical approach allowed to maximise the production of ethanol from non-sterilised sugar beet molasses using *Saccharomyces cerevisiae* while scaling up the experimental results up to a 100 L bioreactor scale [17].

3. Food Waste Valorization for Food and Feed Production

Feedstock and food waste, mostly represented by agricultural sources, can be used in single cell protein (SCP) production and are suitable as protein supplements in either food or feed [21]. Single cell protein technology carried out by microorganisms is designed to solve worldwide protein shortages, and it has shown a great advantage because it is independent of climate, soil characteristics and, not the least, on available land [28]. Moreover, concerns regarding the ethical and environmental implications of meat consumption have increased the demand for meat substitutes. Recently, the use of filamentous fungi as a commercial food product has gained considerable attention, due to its high protein content, the presence of essential amino acids and easy digestibility [29].

A solid-state fermentation (SSF) process carried out by the edible fungus *Neurospora intermedia* using bread waste as feedstock for the production of a protein-rich food product has been investigated by Brancoli et al. [30]. The study proposed the SSF process to be implemented as a stand-alone business, or on-site in small-scale bakeries to recover their otherwise discarded surplus bread and has integrated environmental considerations of the development of a fungal food product, showing which scenario has the best environmental performance and highlighting trade-offs and the parts of the process that are hotspots and should be in focus when optimizing the process. The research can contribute to a sustainable way to handle wasted bread, consistent with a circular economy, and it provides a broader base for the developers of the technology to make sustainable decisions during process optimization [30].

Food waste valorization is also addressed to their bioconversion in animal feed. Tropea et al. [14] reported a fermentation process using non-sterilized fish wastes, supplemented with lemon peel as a filler and prebiotic source, carried out by combined starter cultures of *Saccharomyces cerevisiae* and *Lactobacillus reuteri* for bio-transforming these by-products into a high protein content supplement, rich in healthy microorganisms, for aquaculture feeds. The final fermented product, low in spoilage microorganisms and rich in healthy microorganisms, showed a content of protein and lipids suitable for aquafeed, reducing the problem of a lack of protein sources for aquaculture by encouraging the conversion of fish waste and lemon peel into feed [14].

An interesting review on the utilization of pomaces, waste generated from the pressing of fruits and olives to obtain juices and olive oil, was reported by Munekata et al. [31], where the valorization of this waste as a feed supplement for animal production was deeply investigated. The advances in incorporating and optimizing the use of pomaces in animal feed by generating silages and feeds that improve animal health represent a relevant alternative to using fermented pomaces. Growth performance can be affected, whereas animal health status can be improved. The absence of negative effects and the improvement in the nutritional quality of the foods obtained from animals fed with fermented pomaces is another favorable characteristic to support this strategy [31].

The evaluation of the effects of the feed obtained via fermentation on final consumers was investigated by Panyawoot et al. [32]. Their study has been evaluated the effect of fermented discarded durian peel, a seasonal fruit growing widely in tropical countries, with *Lactobacillus casei*, cellulase, and molasses separately or in combination in total mixed rations on feed utilization, digestibility, ruminal fermentation, and nitrogen utilization in growing crossbreed Thai Native–Anglo-Nubian goats. The study showed that the discarded durian peel fermented with a combination of molasses and *L. casei* had significantly greater nutrient digestibility and propionate concentration, while estimated methane production, the acetate-to-propionate ratio and urinary nitrogen decreased when compared with untreated discarded durian peel. Therefore, a combination-treated discarded durian peel with molasses and *L. casei* could add 25% of dry matter to the diet of growing goats without a negative impact [32].

4. Crude Enzymes, Nutrient Supplements and Biopolymers Production from Food Waste

Agricultural or animal food wastes, thanks to their natural composition, can represent an important substrate to be used as a source of enzymes, food-grade pigments, nutrient supplements, or biopolymers. Munekata et al. [31] reported an interesting review on the use of pomace from food processing for the production of high-addedvalue products via fermentation processes as a strategy applied to obtain carotenoids, fatty acids, linolenic acid, and polyphenols. The authors reviewed, in terms of industrial processes, the production of high-added value products, in particular from grape, apple, and olive, such as enzymes and organic acids for application in food processing as well as in other areas of relevant application such as the development of functional foods or the production of volatile compounds for improving the aroma of food products. The review also highlights the limitations in terms of industrial application and the additional studies that are required to define strategies for using the high-added value compounds obtained from the fermentation/biotransformation of pomaces in the development of food products [31].

The ability of "generally recognized as safe" (GRAS) microorganisms to secrete enzymes extracellularly along with featuring properties, such as high catalytic activity and reaction rate, has been demonstrated in the study of Lappa et al. [33]. The study indicates the successful development of a novel cheese whey valorization approach within the concept of circular bio-economy. A two-stage operation was established to generate crude enzymatic consortia via fungal solid-state fermentations with *Aspergillus awamori*. Fermentation conditions were optimized, and a novel biocatalyst was effectively secreted, and subsequently implemented to hydrolyze whey lactose, formulating a nutrient substrate for fermentative bioconversions. Bacterial cellulose production was also conceptualized as a transitional compound for subsequent functional food formulations, along with the protein fraction, to complement the sustainability and circularity of the process [33].

Another interesting study aimed to promote an integrated bio-refinery approach fully exploiting discarded whey from buffalo milk has been carried out by Alfano et al. [34]. In their work, they evaluated the permeate and retentate of ultra-filtered whey, both provided by a local dairy factory in the Campania region, where cheese manufacturing is one of the main industrial activities in the food sector. The permeate was further processed to investigate a potential downstream approach for obtaining reusable water with a low organic load. The retentate was evaluated to identify further potential biotechnological applications of buffalo milk whey. In particular, it was investigated as the main substrate for the growth of a probiotic strain showing several potential biomedical usages, *Lactobacillus fermentum*. Furthermore, it was investigated for the identification of active molecules for tissue repair induction by using wound healing assays on mammalian cells. The study pointed out that the concentrated ultra-filtered retentate could represent suitable support for the growth of probiotic strain, *Lactobacillus fermentum*, having an adequate sugars and proteins content; moreover, it was demonstrated to stimulate epidermis (keratinocyte) regeneration and therefore meaning potential applicability as an ingredient in skincare products [34].

The production of microbial pigments as bio-pigments for the food industry has been gradually increasing, and the evaluation of whey as an alternative low-cost sustainable fermentative substrate has been investigated by Mehri et al. [35]. The study refers to the production of red colour pigment by *Monascus purpureus* suitable for the food industry, using raw, demineralized and deproteinized whey as substrates by simultaneous hydrolysis and fermentation. The authors carried out interesting research on the evaluation of several factors affecting pigment production, such as fermentation pH, initial lactose concentration, monosodium glutamate (MSG) concentration as the nitrogen source, inoculation ratio, mycelial development, and pigment synthesis kinetics of the microorganism employed. This study pointed out that demineralized whey is a sustainable substrate in the fermentation process of the *M. purpureus* red pigment [35].

The use of a biosurfactant produced by *Bacillus cereus* as an additive in a cookie formulation, evaluating the nutritional benefits of its addition, the non-toxicity, the antioxidant potential and the effects on the physicochemical properties as well as the texture of the product has been reported by Durval et al. [36]. The study demonstrated that the biosurfactant produced by *B. cereus* grown in a medium containing waste frying oil has the potential to be used as a bioemulsifier in food systems. The addition of the biosurfactant in the formulation of cookies showed no drastic changing in the final product as the biosurfactant-containing formulations showed energetic and physical characteristics similar to those of the standard formulation. The biosurfactant was non-toxic and showed considerable antioxidant activity. Moreover, it demonstrated promising results as an ingredient for a flour-based product in terms of the physical, physicochemical, and textural properties of the cookies formulated, also ensuring good preservation [36].

Asimakopoulou et al. [18] carried out a study by assessing wheat straw from Greek agricultural residues as a feedstock for the growth of the heterotrophic microalga *Crypthecodinium cohnii* and the accumulation of polyunsaturated omega-3 fatty acids (PUFAs), more specifically docosahexaenoic acid (22:6n-3,DHA). The work reports an efficient, holistic approach for the integrated valorization of all sugar-containing fractions of biomass towards the production of this valuable product through fermentation, representing the first report demonstrating, as a proof of concept, the valorization of all sugar streams towards the production of omega-3 fatty acids from non-edible sources [18].

Food waste valorization through fermentation processes represents an interesting way of obtaining new value-added products in the cosmetic and pharmaceutical fields also. Ferracane et al. [37] carried out a study aimed to produce and evaluate the different ripening stages of soaps produced with non-edible fermented olive oil (NEFOO soap), evaluating the pH, color, and solubility. The results obtained were compared with those obtained from soaps produced with extra virgin olive oil (EVOO soap). The study pointed out an innovative method to produce “alternative” olive oils on a large scale, exploiting non-edible drupes currently used to produce fodder, natural fertilizer, and energy biomass [37].

The glucan and pectin contents detected in the green husks of walnuts grown in two different soil and climate areas of Southern Italy (Montalto Uffugo e Zumpano) were investigated for potential use in food, cosmetics, and pharmaceutical fields by La Torre et al. [38]. The authors reporteda biovalorization of this waste material in their study and also investigated the spectroscopic, morphological and thermal characterizations of the extracted high-value compounds in order to evaluate if the different pedoclimatic conditions of the two areas could affect both the content of glucans and pectins and their functional uses [38].

Finally, a new perspective on the bioremediation of industrial effluents was demonstrated by Costa et al. [39]. In the study, the authors reported the implementation of *Aspergillus oryzae*, a fungal strain widely exploited as an amylase producer, for the bioremediation of starch in industrial paper mill wastewater by carrying out submerged fermentation technologies (SmF) and solid-state fermentation (SSF). *A. oryzae* was found to grow on non-conventional media such as paper mill wastewater. The SSF of *A. oryzae* was performed on rice hulls. In the bioremediation of paper mill wastewater, for removing starch, the fungus maintains its amylase activity and uses reducing sugars as metabolic substrates [39].

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