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Editorial

Functional Foods and Bioactive Compounds through Environmentally Benign Emerging Processes

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Functional Food demonstrates a wide spectrum of physiological benefits and reduces the risks of several health hazards to consumers; however, its appearance is similar to conventional food and is considered as part of the regular diet. The term "Functional Food" was first introduced in Japan in the mid-1980s, and up to July 2002, nearly 300 food products were granted as functional food for health wellbeing in Japan. Due to the deficiency in a universally accepted term for "Functional foods", wide ranges of terms are being used around the globe. Traditionally, it was known as dietary supplements or fortified foods; however, synonyms for functional foods are nutraceuticals, designer foods, medifoods, vitafoods, and many more [1]. As time progresses, increasing consumer consciousness about regular wellness with a proper diet is a considerable paramount factor for boosting the functional food sector. It was estimated that, globally, the size of the functional food market accounted for USD 129.39 billion in 2015 [2] and USD 353 billion USD in 2019 [3].

Bioactive compounds, often referred to as functional ingredients, are biomolecules within edible and non-edible parts of food and agricultural matrices, which have unique physiological contributions. However, probiotic-fortified foods were considered to be a functional food; presently, wide ranges of biomolecules have ushered health-conscious consumers to a new fraternity of sophisticated consumers, conscious of regular wellness. Common bioactive compounds include non-digestible carbohydrates, proteins, peptides, essential amino acids, parabiotics, postbiotics, omega-3 fatty acids, structured lipids, secondary metabolites, and many more from various living sources [4]. Numerous opportunities for bioactive compounds have catapulted functional foods to the forefront of a wide range of food industries. In industry, functional foods are produced by modification and fortification of conventional foods. On the other hand, bioactive compounds can be extracted from natural and living sources. Furthermore, bioactive compounds can be produced from the conversion of native molecules by enzyme and microbe-assisted processes. In most cases, extracted bioactive compounds are incorporated in the food matrix to improve the nutritional standard of food. Technologies related with the formulation of functional foods and isolation of bioactive compounds from living sources are classified into the following categories [5].

(A) Pretreatment

(a) Physical treatment:

Conventional: milling, thermal treatment (drying), mechanical pressing, maceration, moderate-speed centrifugation (5000–30,000 rpm), freeze drying, and microfiltration.

Emerging: foam mat drying, electro-osmotic dewatering, and low-temperature plasma treatment.

(b) Physico-chemical treatment:

Conventional: steam explosion, ammonia fiber explosion or expansion, CO_2 explosion, and hot water treatment with high pressure.

(c) Chemical treatment: acid treatment, alkali treatment, oxidative delignification, ozonolysis, organosolv, and wet oxidation

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Citation: Nath, A.; Vatai, G.; Bánvölgyi, S. Functional Foods and Bioactive Compounds through Environmentally Benign Emerging Processes. *Processes* **2023**, *11*, 1182. https://doi.org/10.3390/pr11041182

Received: 3 April 2023
Accepted: 4 April 2023
Published: 12 April 2023

(d) Biological treatment: enzyme treatment and microbial degradation.

(B) Macro and micro-molecule separation:

Conventional: alcohol precipitation, isoelectric precipitation, roasting, and ultrafiltration.

Emerging: ultracentrifugation (>70,000 rpm), density gradient centrifugation, differential centrifugation.

(C) Extraction

Conventional: hydro-distillation, steam distillation, Soxhlet extraction, Kumagawa extraction, and vacuum distillation.

Emerging: microwave-assisted extraction, ultrasonic-assisted extraction, high hydrostatic pressure-assisted extraction, high-pressure homogenizer-assisted extraction, and high-voltage electrical discharge-based extraction.

(D) Isolation

Conventional: nanofiltration, electrodialysis, and adsorption chromatography.

Emerging: magnetic particle-assisted extraction, aqueous two-phase separation, and ion-exchange membrane chromatography.

Conventional technologies have lost their optimum performance because of rising demands from consumers and inefficient yield. In this regard, several technologies were developed to reduce the limitations of conventional technologies. They are categorized as emerging or advanced technologies. The terminology "Emerging" has no specific feature other than its outlook towards the advancement of conventional technology. The developed advanced technology may have a lower equipment footprint with high throughput, can be energy-efficient, and so on. Furthermore, de novo synthesis of biomolecules from precursors via the enzyme and microbial route can be considered an emerging approach. Without any contradiction, developed emerging technologies can intensify the process and are more environmentally friendly than conventional ones. Some examples for the development of functional foods and bioactive compounds are mentioned here; however, they are not limited.

Application of oven heat–moisture treatment (OHMT) and autoclave heat–moisture treatment (AHMT) to purple rice (*Oryza sativa* L. *indica*) flour resulted in a decrease in swelling capacity, solubility, and rapidly digestible starch (RDS) but an increase in resistant starch (RS) and slowly digestible starch (SDS) compared to untreated flour. Furthermore, both treatments increase the relative crystallinity of flour, which may provide resistance to enzymatic digestion and a slower release of glucose. Therefore, one may feel that treated flour could be used as a source of RS to produce healthy foods (pasta, bread, biscuits, and crackers) for diabetic consumers [6]. Another example is pulping strawberries before freeze-drying (FD) and increasing the drying temperature from 20 °C to 60 °C, significantly reducing the FD time; however, this has little influence on the total phenolic content (TPC) and ascorbic acid (AA) but decreases the lightness, redness, and yellowness of the dried fruits. The obtained strawberry powder can be used for the fortification of various kinds of foods, such as snacks, cookies, candies, and ice cream [7].

Bioactive compounds with functional activities can be produced via several emerging processes, including enzyme- and microbe-based biotransformation. These approaches have been suggested to be "safe" by the U.S. Food and Drug Administration (FDA). Biotransformation to a new biomolecule with unique biological activities and the application of beneficial microbes to develop new bio-formulation with improved biochemical activity and nutritional status may be considered as emerging environmentally benign processes.

Prebiotic galacto-oligosaccharides (GOSs) can be produced from lactose via a trans-galactosylation reaction. The mentioned concept is not only well accepted by the members of the lactose-intolerant community, as the application of prebiotics in regular foodstuffs provides numerous health benefits to consumers. To avoid the limitations of GOS production from a conventional stirrer tank batch bioreactor, a bioreactor associated with an ultrafiltration membrane module in a continuous mode with enzyme (Biolacta N5) recovery may bring a boon. In the membrane-integrated bioprocess, enzyme recovery by the membrane unit may reduce the enzyme loss. Furthermore, continuous addition of lactose in the reaction tank and collection of saccharide blend from the permeate end may reduce the influence of inhibitors in the biochemical reaction. Both the rates of GOS production and lactose conversion were declined gradually from initial cycle to cycle five, and within five cycles, the half-life of the enzyme was estimated to be ca. 15 h [8]. Hypoallergenic peptides can be produced from liquid milk protein concentrate (LMPC) by sequential tryptic and microbial hydrolysis; however, milk proteins are members of the "big 8" allergens. LMPC can be produced by de-watering milk via a membrane filtration process. The filtration process can be intensified (high permeation with lower energy consumption) by the addition of a mechanical device, known as a static turbulent promoter. Additionally, milk-protein-derived peptides may influence the renin–angiotensin system, which is closely related to oxidative stress and inflammation. It has been proven that synthesized peptides from LMPC offer more antioxidant potency, anti-angiotensin activity, and antibacterial activity than native protein [9].

However, probiotics have been considered as a member of functional food for a long time; their implementations, apart from food formulations, have opened a new arena in the biopharmaceutical and cosmetics industries. New cosmetic ingredients having skin-moisturizing, skin-whitening properties, and antioxidant activity can be produced through a combination of probiotic lactic acid bacteria *Limosilactobacillus reuteri* ferment filtrate with naturally occurring organo-mineral rock alginite minerals. It may be realized that lactic acid from lactose via probiotic culture combined with humic acid and fulvic acid in alginite improves the mentioned biochemical activities of the cosmetic formulation [10].

Microencapsulation of bioactive compounds is an emerging concept. It has been explored in order to satisfy the increasing expectation of developing food ingredients with complex properties and functional values. In microencapsulation technology, small droplets of liquid or solid particles are coated within a thin film, known as wall material or matrix. Presently, the microencapsulation of polyunsaturated fatty acid pigments and other bioactive compounds has received great interest in the food and biopharmaceutical industries [11,12] because it can protect encapsulated bioactive compounds from degradation and control their release in the environment, food matrix, and gastrointestinal tract during digestion.

Presently, the management of food waste is taken into great consideration because it has been discovered that food wastes significantly affect the sustainability of the food system. It is estimated that yearly, about 1.3 billion tons of food is wasted globally, representing approximately one-third of the food produced for human consumption [13]. The Food and Agriculture Organization (FAO) of the United States reported, in 2019, that harvest, industrial processing, retail, and the final consumption stages are responsible for producing 11–23%, 17–19%, 8–17%, and >50% of food waste, respectively [14]. On the other hand, a report from the United Nations Environment Programme (UNEP) showed that 17% of total global food production is wasted in several ways, such as 2% in retail, 5% in the food service, and 11% in households. Wide differences occur between regions of the world. For example, in developing countries (6.2 billion people), less than 630 million tons of food is discarded, while in developed countries (1.4 billion people), 670 million tons of food is wasted [15]. Waste from food processing is rich in carbohydrate, protein and lipid are generally used as animal feed, while, globally, ~3 billion cannot afford a healthy diet, and 690 to 829 million people remain hungry. However, food waste can be converted into edible forms to help solve the dilemma of the hunger problem; thus, the attention of the food industry has been moved towards a new direction in the past two decades. Approaches to valorization of food wastes have been modulated to recover bioactive compounds from food waste and their biotransformation. It may be realized that a significant income from bioactive compounds has been taken into consideration along with the marketing of edible foods [16].

Hass avocado kernel is a major agri-food by-product; however, it has a pharmacological effect due to being enriched with fatty acids, polyphenols, and sterols. Roasted Hass kernel flour can be used in different food applications, including pastries and coffee.

Roasting of Hass avocado (*Persea americana* Mill) kernel at a temperature of 180 °C for 30 min significantly improved the oil extract, crude fiber, total phenolic compounds, Ca, K, P, Na, Zn, browning index, and redness/greenness; however, crude protein, total flavonoids, Fe, antinutrients, lightness, and yellowness/blueness were after roasting. Furthermore, volatile compounds could be increased and, among them, esters may be the most common volatile compound. Roasting is a heat treatment process, which modulates different physico-chemical parameters of foodstuff because of dehydration and chemical reactions depending on the roasting time and temperature. In addition to dehydration, a significant biochemical reaction during roasting is the Maillard reaction, which is responsible for many changes, including increasing the bioavailability, breaking down some antioxidant components, creating new biomolecules with free radical scavenging activity, and producing a derivative aroma [17].

Another agri-food by-product is red wine grape pomace, resulting from white wine production, an untapped source of valuable bioactive phenolic compounds (phenolic acids, flavonols, flavones, and polymeric phenols), playing a significant role in the functional food, beverage, nutraceutical, and cosmetic industries. Phenolics can be recovered from unfermented cabernet sauvignon pomace via an alkaline hydroethanolic solvent using a two-stage countercurrent extraction process. The countercurrent process could reduce the fresh water usage in a significant way and increase the total phenolic compounds with antioxidant activity [18].

Recently, a promising emerging technology such as an ultrasonic device was used in food processing. Ultrasonic waves are characterized as a sound wave with frequency ranges from 20 to 100 kHz, while intensities are in a range of 10 to 1000 W/cm^2. Based on the ultrasonic wave frequency spectrum, it can be used for different purposes in food processing. For example, high-power and low-frequency ultrasonic systems enhance food product quality, while ultrasonic low-power and high-frequency systems are used for non-destructive assessments of the physicochemical properties in foods. Ultrasonic technology is suitable for handling both solid and liquid foods and consumes lower power. In the food industry, ultrasound is used for the dissolution and crystallization, mixing and homogenization, activation/deactivation of enzymes, decontamination of microbes, hydrogenation, stabilization, tenderization of meat, emulsification, dispersion, and enhancement in extraction. Recovery of phytoconstituents using ultrasound-assisted extraction in the context of valorization of food waste is noteworthy because bioactive compounds stay within the complex lignocellulosic matrix. Ultrasound creates cavitation, and the developed cavity grows in size, followed by collapsing unexpectedly with the release of energy. As a result, local temperature and pressure are increased. Close to a solid boundary, cavity collapse is asymmetric and produces high-speed jets of liquid, which promote disintegration of cellular layers and enhance the penetration of the solvent into cellular materials. As a consequence, permeation of bioactive compounds into the bulk medium is enhanced. Furthermore, physical effects, such as liquid circulation and turbulence produced by cavitation, help in increasing the contact surface area between the solvent and targeted compounds by boosting the penetration of the solvent into the matrix [19].

Fractionation of proteins from whey, a major by-product of cheese processing, has received attention because the marketing of isolated whey proteins along with dairy foods may boost the profit of the dairy industry. In the cutting-edge research area of bioseparation engineering, membrane chromatography (MC) is an emerging bioseparation technology combining the principles of membrane filtration and chromatography. Purification of proteins via the MC process is dependent on the functional groups in adsorbents or ligands in the membrane and their binding/elution capacity with proteins. Advantageously, MC processes can be operated with a high volumetric flow rate and lower pressure drop. In the MC process, transport of proteins to a stationary phase is directed by convection and minimum pore diffusion. Therefore, mass transfer resistance is reduced and protein recovery is facilitated. Disposable membranes are used in the MC system, which reduces the generation of wastewater caused by conventional membrane cleaning steps. Furthermore, there is no emission of any greenhouse gasses during the fractionation of protein from whey via MC processes [20].

The functional foods market is one of the fastest-growing industries, promoting multidisciplinary research. Bioactive compounds play a key role in the nutritional status of functional foods. However, the concept of functional food was introduced a long time ago, and the demand has an increasing trend with increasing population to maintain regular wellness. To satisfy the demand of consumer development of emerging processes, great consideration has been observed. Without any hesitation, emphasis has been placed on designing emerging processes with the aid of better productivity from lower equipment footprints and processing costs, utilization of by-products from different process industries, and reducing environmental hazards. Research and implementation in these aspects shall be moved and upgraded in both academic and industrial sectors with increasing population and demand.

Author Contributions: Writing—original draft preparation, A.N., G.V. and S.B.; writing—review and editing, A.N. and G.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: A. Nath acknowledgments Hungarian Bi-lateral postdoctoral scholarship. Authors acknowledge the project 'Preparation for the transition to circular economy in the case of agricultural and green waste' of Environment and Energy Efficiency Operational Programme grant scheme of Ministry of Technology and Industry Hungary under grant no.: KEHOP-3.2.1-15-2021-00037.

Conflicts of Interest: The authors declare no conflict of interest.

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