sustainability

Review

Advances in the Food Packaging Production from Agri-Food Waste and By-Products: Market Trends for a Sustainable Development

Nathana L. Cristofoli [1,†], Alexandre R. Lima [1,†], Rose D. N. Tchonkouang [1], Andreia C. Quintino [2] and Margarida C. Vieira [1,2,*]

[1] MED—Mediterranean Institute for Agriculture, Environment and Development & Change—Global Change and Sustainability Institute, Faculty of Sciences and Technology, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal; nlcristofoli@ualg.pt (N.L.C.); carlima@ualg.pt (A.R.L.); rdtchonkouang@ualg.pt (R.D.N.T.)
[2] Department of Food Engineering, High Institute of Engineering, Universidade do Algarve, Campus da Penha, 8000-139 Faro, Portugal; anquintino@ualg.pt
* Correspondence: mvieira@ualg.pt
† These authors contributed equally to this work.

Abstract: Agricultural waste has been a prominent environmental concern due to its significant negative impact on the environment when it is incinerated, disposed of in landfills, or burned. These scenarios promoted innovations in the food packaging sector using renewable resources, namely agri-food waste and by-products such as bagasse, pulps, roots, shells, straws, and wastewater for the extraction and isolation of biopolymers that are later transformed into packaging materials such as bioplastics, biofilms, paper, and cardboards, among others. In this context, the circular bioeconomy (CBE) model is shown in the literature as a viable alternative for designing more sustainable production chains. Moreover, the biorefinery concept has been one of the main links between the agri-food chain and the food packaging industry. This review article aimed to compile recent advances in the food packaging field, presenting main industrial and scientific innovations, economic data, and the challenges the food packaging sector has faced in favor of sustainable development.

Keywords: food waste recovery; circular bioeconomy; biorefinery model; sustainable food packaging

Citation: Cristofoli, N.L.; Lima, A.R.; Tchonkouang, R.D.N.; Quintino, A.C.; Vieira, M.C. Advances in the Food Packaging Production from Agri-Food Waste and By-Products: Market Trends for a Sustainable Development. *Sustainability* **2023**, *15*, 6153. https://doi.org/10.3390/su15076153

Academic Editor: Dario Donno

Received: 13 March 2023
Revised: 26 March 2023
Accepted: 29 March 2023
Published: 3 April 2023

1. Introduction

There is a growing demand for more sustainable routes for the food packaging industry that can replace non-renewable raw materials, such as petroleum-based polymers, with bio-based materials. The recovery of agri-food waste and by-products and the development of industrial units of biorefinery to process and convert such raw materials into biomaterials with high-added value and applicability to produce sustainable packaging can be a solution for the food packaging sector to achieve sustainability.

The composition of organic waste is an environmental and human health problem, considering that its disposal in landfills is responsible for the production of methane and leachate due to the high organic load [1,2]. In this sense, innovating through the management and recovery of waste and by-products of the food industry by converting them into feedstocks for use as packaging materials is a solution to reduce the disposal of organic waste, namely solid waste and wastewater [3,4].

Global perceptions of the use of agricultural and industrial waste for resource conservation have undergone a substantial shift due to the transition from a linear to a circular economy [5]. The circular economy (CE) concept was introduced by policymakers from the European Union (EU) and China to address the global environmental challenges by closing the loop of the product lifecycle, considering the urgent need for a healthier and sustainable ecosystem [6,7]. A closed (circular) loop where materials are consumed, reused, and recycled while providing extra value or maintaining the value of the material throughout various lifecycles and minimizing waste generation is the fundamental idea of a circular economy [8,9]. Similarly, the circular bioeconomy model emerges, which goes beyond combining the concepts of bioeconomy and circular economy to propose a circular economy as a replacement for linear flows of materials and nonrenewable resources by exploring biologically-based products and services such as valuing agricultural waste and by-products [10–13]. By addressing several objectives for sustainable development, the circular bioeconomy stands out as a key concept for sustainability [11,14,15]. Figure 1 illustrates a circular bioeconomy model, which includes biorefineries for recovering agri-food waste and by-products as renewable raw materials to produce biomaterials with potential applications in the food packaging industry.

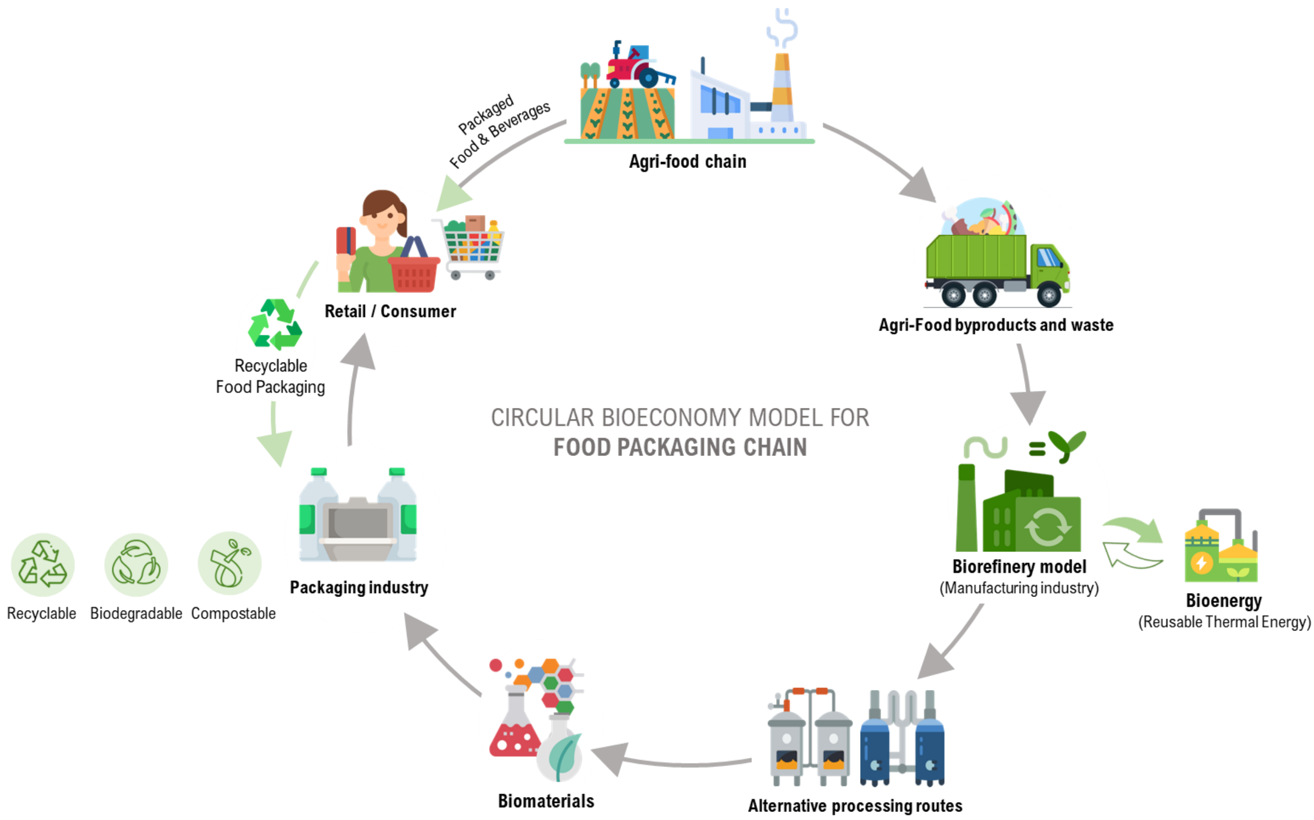

Figure 1. Circular bioeconomy model applied to food packaging industry integrated into the biorefinery to recovery of agri-food waste and by-products.

According to Figure 1, a circular loop involves recovering raw materials from agri-food waste and by-products to be used as suitable packaging biomaterials. After being discharged, packages made of these biomaterials are further processed so that they can be returned to nature and reverted to raw materials again [5]. These bio-based materials possess biodegradable properties, which provide new end-of-life routes, such as organic recycling by aerobic or anaerobic degradation, agricultural mulching, solubilization, or environmental biodegradation, reducing waste accumulation and environmental pollution [16].

Part of this loop is the concept of food waste biorefineries, which, in recent years, has been at the forefront of the technological development for food waste recovery [17]. As far as profitability is concerned, each biorefinery has its particularities, especially in the case of food waste biorefineries. According to Jorissen et al. [18], industrial and municipal food waste processing has slight economic advantages over the processing of agricultural waste because it has a lower market value. Other associated costs, such as logistics, storage, and operational capacity, are crucial factors for the economic viability of a biorefinery. As a first step, to develop a robust deterministic dynamic analysis laboratory test to model, the kinetics of the process should be considered. Moreover, Banerjee et al. [19] suggest that in order for a biorefinery to be economically sustainable, it requires a multi-feedstock plant that is capable of overcoming factors such as raw material seasonality and that operates in a model with a constant supply of biomass. Therefore, in regard to the biorefinery concept, the processing of agri-food waste and by-products has been considered a promising, economically viable, and sustainable approach to producing biomaterials for food packaging [20].

The purpose of this article was to review the main innovations and research trends related to the use of agri-food waste and by-products for the development of biomaterials suitable for technological applications in the production of sustainable food packaging. In addition, it is important to address challenging issues such as economic feasibility and the positive impact that the transformation of the food industry has on environmental sustainability to understand how the concept of biorefineries and a circular bioeconomy can be competitively applied in the industry. In this review, we draw a logical parallel between industry and science to provide useful guidelines for food packaging technology.

2. From Food Waste and By-Products to Packaging

The conversion of agricultural biomass into marketable goods for the food and animal feed industries often generates by-products, residues, and organic waste [21]. Rezaei and Liu [22] reported that more than 50% of fresh fruits and vegetables are lost or wasted during post-harvesting, processing, storage, and consumer use. Generally, by-products are disposed of in the form of pomace, which consists of pulp, peels, seeds, and stems and is a valuable source of polysaccharides, proteins, pigments, and phenolic compounds that have been proposed as a substrate for a number of applications [23].

In general, agri-food wastes and by-products were undervalued, but this scenario has changed, as they are one of the most attractive options that can be used as raw materials to produce biodegradable packaging and improve their performance [20,24]. The conversion of food waste usually requires a pre-treatment step where complex food waste is broken down into subcomponents. These agricultural wastes may be processed to produce fiber and polymers, which can be used in packaging applications such as bioplastic packaging, trays, containers, disposal packaging, and food coating [25].

Using bio-derived materials is advantageous because they are derived from agricultural sources and are renewable, nontoxic, and capable of being recycled, which results in reduced costs. The development of packaging materials using renewable sources for the development of biodegradable materials must, however, consider all potential food safety threats despite their biological origin, while at the European level, these products must comply with the EFSA (European Food Safety Authority). Several researchers have investigated the use of agri-food waste biomass to produce sustainable packaging, as shown in Table 1.

Table 1. Biomass from agri-food industries and their food packaging applications.

Name	Food Packaging Applications	Reference
Sugarcane bagasse	Disposable cups, plates, and carton boxes Polylactic acid (PLA) Polyhydroxyalkanoate (PHA) Polyurethanes Bio-polyethylene Starch-based nano-cellulosic bioplastics Carboxymethyl cellulose (CMC) biofilm Coating films	[26] [27] [28]
Rice straw	Disposable cups, plates, and carton boxes	[26]
Rice husk	CMC biofilm	[27]

Table 1. *Cont.*

Name	Food Packaging Applications	Reference
Cocoa pod husk	Cellulose bioplastic film	[29]
Wheat straw	Polyhydroxy-co-3-butyrate-co-3-valerate (PHBV)/wheat straw fibers composite films	[30]
Corn waste	Biomaterials (paper and cardboard)	[31]
Cassava peels	Starch-based bioplastics Cellulose-based bioplastics PLA Poly hydroxybutyrate (PHB)	[32]
Banana peels	Starch-based bioplastics Cellulose-based bioplastics PLA PHB	[32]
Tomato peels	Cutin-based edible films Active bio-composites	[33] [34]
Apricot, cherry, and grape pomace	PHA	[35]
Crustacean shells waste	Chitin-based bioplastic Nanostructured film	[32]
Pomegranate peels	Films	[36]
Avocado seeds	Starch-based biofilms	[37]
Fish skin	Active films Gelatin	[38]
Spent coffee grounds	Phenolic compound PHA/PHB	[39]
Olive pomace	Gelling agent	[40]
Olive leaves and pomace	Active film	[41]
Grape pomace and olive leaf	Antioxidant film	[42]

As a result of the pomegranate industry, a leftover pomace consisting of approximately 73 wt% peels containing 7.6 wt% of pectin, which is obtained upon extraction and can be used to improve the tensile strength and modulus of films at a concentration of 6%, was produced [36]. Kaisangsri et al. [43] described foam trays made from cassava starch (30%) combined with natural fiber polymers and chitosan (4%); they displayed similar characteristics to those of polystyrene foam. The production of edible coatings and films based on mango waste was reported by Torres-León et al. [44]. The authors used peels and kernel extracts with antioxidant properties and glycerol as a plasticizer, resulting in a film material with suitable antioxidant and barrier properties to extend the shelf life of peaches. Sugarcane bagasse was used for the production of lignin, which achieved a 20.4% yield, was tested as a fruit coating, and showed higher antifungal activity than limes coated with commercial lignin [28]. Another study reported the development of rice straw paper packaging with antibacterial activity derived from longan (*Dimocarpus longan*) peels [45].

Follonier et al. (2014) studied the conversion of apricot, cherry, and grape pomace waste into fermentable monosaccharides, which were used as an energy source for bacteria that produce intracellular polyesters known as polyhydroxyalkanoates (PHAs) (a total of 21.3 g PHA/L was obtained from grape pomace and 1.4 g PHA/L from apricot pomace), which are a promising substrate of residual sugar content that produces PHA in a sustainable way. Oil extracted from spent coffee grounds can also be used as a substrate for the production of PHA and PHB. Obruca [39] reported the high productivity of PHB (0.82 g PHB/g of oil, 49.4 g/L), while Cruz et al. [46] reported 0.77 g/g and 13.1 g/L of PHA production. The examples above demonstrate how the inherent qualities of some food by-products can be used to enhance the functionalities of the final packaging product, often without the introduction of any additional additives [47].

2.1. Biopolymers for Food Packaging

The bio-based biodegradable polymers derived from agri-food waste feedstocks allow the reduction of the environmental impact associated with food waste and non-biodegradable food packaging materials [4]. They can be categorized into protein-based, starch-based, cellulose-based, chitin-based, lipid-based, and microbial-based materials and are presented in the next section [48].

2.1.1. Protein-Based Biopolymer Packaging

Several protein-based materials have been produced so far using a variety of animal and vegetable proteins. Wheat protein (gluten), soy protein, and corn protein (zein) are the main sources of proteins for bioplastic material production, presenting the advantage of being abundant, inexpensive, and renewable sources for the manufacture of biodegradable food packaging films [49,50].

Wheat gluten, a by-product of wheat processing, presents good oxygen and carbon dioxide barrier properties [51]. Soy protein bioplastics have typically demonstrated adequate mechanical properties (tensile strength); however, they have been criticized mostly for their low water resistance due to their high content of polar amino acid residues (aspartic, glutamic). Zein, a by-product of corn processing, is a major storage protein and contributes to the production of strong films with exceptional flexibility and compressibility and a good water vapor barrier that is used as active packaging for foods [52–54]. However, the resultant film is brittle under dry conditions, and this limits its application as a free-standing film or as a coating material [52]. Even though protein-based biomaterials have proven to be fast-degrading biopolymers [55], only a few of them have any real impact because of their defined industrial scale-up, high assembly costs, and low product performance [56]. Moreover, the limited use of plant-based protein biopolymers is associated with their poor thermoplasticity, water resistance, and brittleness [57]. Nevertheless, it may be combined in various proportions with plasticizers to create an eco-friendly thermosetting composite [58].

2.1.2. Starch-Based Biopolymer Packaging

The major sources of starch include corn, cassava, wheat, rice, pea, tapioca, and potato, which can be used in starch-based bioplastics in the form of native starch, modified starch, or blended with other synthetic polymers [58]. Starch may be used to produce biodegradable food packaging films that include fresh or dried fruits and vegetables [59]. The benefits of starch-based bioplastics (thermoplastic starch) include their low cost, widespread availability, complete compostability without leaving harmful residues, biocompatibility without causing any adverse effects on the biosphere, safety for food contact use, and ability to be processed with conventional plastic processing equipment [59–61]. As for the limitations, their high brittleness and hydrophilicity restrict their applications due to poor mechanical properties and moisture sensitivity. When plasticizers are added to their production, more flexible and less rigid and brittle materials are obtained [62].

Several techniques such as plasticization, blending, derivation, and graft copolymerization have been investigated to overcome the weaknesses of starch-based bioplastics [63]. Graft polymerization can modify the chemical and physical characteristics of starch, making products less hydrophilic and giving them greater tensile strength without affecting their biodegradability [64]. The copolymerization of corn starch increased its heat stability [65]. Cassava-starch-based films incorporated with zinc nanoparticles could be effectively used for packaging tomatoes due to their lower oxygen permeability, hardness, elasticity, and plastic properties [66]. Blending fibrous materials with starch improves the properties of the obtained packaging films. Fitch-Vargas et al. [67] reported that adding sugarcane fiber to the corn starch formulation increased its biopolymer films' tensile strength and water resistance. Cassava fibers added to corn starch increased the film strength by up to 37.5% but reduced the elongation at break, as demonstrated by Travalini et al. [68]. The increased tensile strength was due to strong intermolecular interactions between the cassava fibers and starch, while the reduced elongation at break was attributed to agglomerates that may have developed inside the films [63].

2.1.3. Lignocellulosic-Based Biopolymer Packaging

Lignocellulosic biomass (LB) is the most abundant biopolymer in the biosphere; it is found in trees and waste from agricultural crops and mainly comprised of lignin, cellulose, and hemicellulose [65]. The sources of LB include sugarcane bagasse, corn straw, cotton straw, rice straw, and wheat straw. Lignin has a high carbon content that is suitable for conversion into value-added products, and it is used as an additive in barrier coatings, as active packaging, and even in lignin-based foams [69]. As lignin can function as a plasticizer, stabilizer, or bio-compatibilizer, it is possible to produce bioplastics with high performance and different properties. Lignin was successfully added to a biopolymeric packaging film, improving its mechanical properties and thermal stability [69].

Cellulose is a hydrophilic, highly crystalline, fibrous, and insoluble substance. Cellulose-based materials provide benefits such as edibility, biocompatibility, barrier properties (e.g., against oxygen and moisture), aesthetic appearance, nontoxicity, biodegradability, low cost, durability, strength, and stiffness [70–72]. However, in their natural state, they have limitations in regard to replacing synthetic polymers, scalability issues, and high manufacturing costs [73]. The chemical and surface modification ability of cellulose has been utilized for the processing of cellulose into biopolymers and can be used for packaging applications [70,71,73].

Because of their non-toxicity, superior biocompatibility, high viscosity, transparency, and film-forming capacity, water-soluble carboxymethyl cellulose (CMC) and ethyl hydroxyethyl cellulose (HEC) have gained more attention [71,74]. Yaradoddi et al. [74] investigated the conversion of agricultural-waste-derived CMC (mostly sugarcane bagasse) in a blend with gelatin, agar, and glycerol, and the best features for food packaging applications (the lowest water vapor permeability and the highest biodegradability rate) were found when adding 2% glycerol. Another study by Zhang et al. [75] developed semi-transparent, mechanically strengthened, UV-shielding, antibacterial, and biocompatible films with HEC using polyvinyl alcohol (PVA) and ε-polylysine (ε-PL) as a reinforcing agent and antibacterial agent, respectively.

Lately, cellulose fibers have been converted to nanoparticles characterized by the nanosize of the fibers (<100 nm) and typically classified as CNC (cellulose nanocrystals), CNF (cellulose nanofibrils), and BNC (bacterial nanocellulose) [76,77]. The beneficial characteristics of nanocellulose (NC), such as high crystallinity, a high degree of polymerization, high mechanical strength, low density, biocompatibility, non-toxicity, and biodegradability have aroused interest in their application as a food packaging material [78]. Ultrathin CNF/CNC films were successfully developed by Sun et al. [79], and their porosity, thermal stability, and thermal expansion increased with an increasing ratio of CNFs. Shi et al. [80] developed cellulose-based food wrapping paper with strong barriers and antibacterial properties by building multilayer films on the paper's surface using chitosan and CMC. The resulting multilayer coating increased the mechanical properties of the paper (68.2% decrease in WVP, 192.9% improvement in tensile strength, and 180.4% increase in folding endurance), as well as its barrier properties against grease, oil, water, air, and water vapor. The modified wrapping paper displayed no apparent cytotoxicity, a 95.8% antibacterial rate against *E. coli*, and a 98.9% antibacterial rate against *Staphylococcus aureus*.

2.1.4. Microbial Biopolymer Packaging

Polymers that are produced naturally or genetically from microorganisms have great potential in the production of coatings and films that can be used in packaging materials. The agri-food waste and by-products can be used by microorganisms as feedstock for fermentation in the production of biopolymers [81]. Polyhydroxyalkanoates (PHA) and polylactides (polylactic acid) (PLA), in particular, are the most studied polymers to date and are widely used due to their numerous applications [82]. Figure 2 presents a general

PHA/PLA production flowchart that follows the sustainable concepts of a closed loop and clean production.

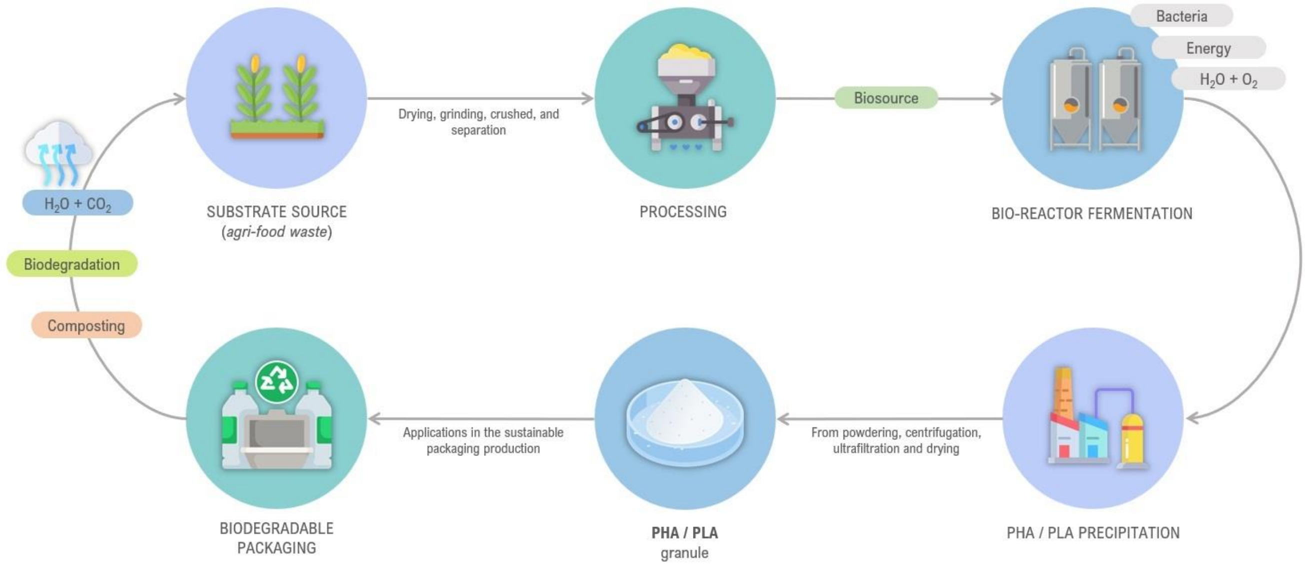

Figure 2. General PHA/PLA production flowchart.

PHAs are considered an alternative material for conventional plastics due to their similarity to petrochemically derived plastics, better hydrophobicity, relatively high melting point, and optical purity [83]. Current research demonstrates the existence of approximately 150 different PHAs [84], which gained worldwide interest because of their biodegradable, biocompatible, non-toxic, and thermoplastic nature; the polymer characteristics are influenced by the number of carbon atoms present in each HA monomer unit [83].

PHA-based films have attracted interest for their food packaging applications, as they can be processed into excellent packaging films via thermoforming using PHAs as the sole material or in combination with other compatible polymers. Based on their degree of crystallinity and elasticity, PHAs can be processed into flexible foils for wrapping or into rigid and robust molded objects acting as containers [85]. Among the PHAs, the production of medium-chain-length PHA (mcl-PHA) has attracted much attention because of its favorable properties, as its extraction, purification, and recycling are easier and cost-effective due to its higher solubility, which is related to its low crystallinity [86]. Awasthi et al. and Pereira et al. [87,88] reported the production of mcl-PHA using watermelon and apple pulp waste as a microbial substrate with desirable mechanical properties that do not require expensive pretreatment or even any modification.

The characteristics of small-length PHA (scl-PHA) limit its application, and several methods have been investigated to improve its mechanical properties. The addition of lignocellulosic biomass and its derivatives as bio-fillers in P3HB revealed a notable improvement in the viscoelastic characteristics of the polymer [89]. Nosal et al. [90] reported that plasticizers significantly affect the mechanical properties of the PHB-V compounds, leading to the increased mobility of the polymer chains and a decrease in rigidity, resulting in a more flexible material with improved deformation capacity, and improving the tensile properties (i.e., tensile strength, elongation at break) and thermal stability of PHB [91].

Although PHAs' packaging application seems promising, it has some drawbacks that hamper its industrial production, including restricted functionality, incompatibility with traditional heat treatment processes, sensitivity to thermal degradation, and particularly high manufacturing costs [84,92]. It is therefore necessary to exploit cheap carbon sources such as agricultural waste for PHA production.

Polylactic acid (PLA) is an aliphatic polyester that can be produced from any fermentable sugar. PLA is one of the most produced and successfully commercialized biopolymers in the market and is considered a GRAS (Generally Recognized as Safe) material [93]. Overall, it is made from corn starch because corn is one of the most available and cheapest sugars globally. However, other sugar-rich plants and crops, such as sugarcane, cassava, sugar beet pulp, and tapioca root, can be used. It is a versatile material that is a thermoplastic, a gas barrier, UV-resistant, biocompatible, elastic, rigid, and hydrophobic, which makes it a possible replacement for several petroleum-based plastics, such as PET and PVC [32,94].

Despite advances in fermentative synthesis technology, PLA's multi-step process makes it an expensive material and puts it at a disadvantage compared with fossil-based plastics [95]. Moreover, PLA has some limitations such as poor toughness, slow crystallization rate, low heat distortion temperature, and poor water barrier properties compared to conventional thermoplastics, in addition to only degrading after months at a high temperature under industrial composting conditions [93,96]. Various approaches, such as combining PLA with other polymers and/or producing PLA with antioxidants, plasticizers, or fillers such as fibers or micro- and nanoparticles, have been used previously with the aim to obtain PLA with improved purity and mechanical and physical properties [97].

Spent coffee grounds were used as a filler for the production of PLA-based biodegradable films that showed increased elongation at break while the hardness and brittleness decreased [98]. Ma et al. [99] developed biodegradable antimicrobial packaging for chilled salmon using PLA/PHB-based films with plasticizers. The results showed that the plasticizers allowed for the production of films with greater oxygen permeability and superior mechanical characteristics than the EVOH-based film, in addition to the packaged salmon having a lower total bacterial count after 15 days. More recently, it was reported that high salinity could increase the optical purity of L-lactic acid produced from the co-fermentation of a mixed substrate of food waste and waste-activated sludge. This may occur because D-lactic-acid-producing enzymes are sensitive to high salt concentrations, allowing high yields of optically pure L-lactic acid ($\geq$99%) as the main PLA precursor [100,101].

2.1.5. Chitin-Based Biopolymer Packaging

Crab shells, shrimp shells, and fish scales are the ideal biomass resources for chitin production [102], while chitosan is obtained by the deacetylation of chitin with natural antimicrobial properties that can also be extracted directly from the cell walls of fungi [102–104]. Chitin and chitosan are highly appealing, renewable resources for bioplastics because of their abundance, biodegradability, film-forming characteristics, nontoxicity, and biocompatibility [105].

Pandharipande and Bhagat [106] employed chitin extracted from crab shells to synthesize a bioplastic film that may be used to produce straws, cups, containers, and photoprotective films. Another study reported that chicken meat packed with chitosan and chitosan/CNC films showed lower counts of *Pseudomonas* and *Enterobacteriaceae* bacteria during the first days of storage at 4 °C, in comparison with commercial membranes. In addition, meat packed with chitosan/CNC films resulted in the lowest value of total volatile basic nitrogen (an indicator of meat spoilage) after 14 days of storage, indicating the efficiency of chitosan/CNC films in reducing the spoilage rate [107]. Rubilar et al. [108] reported an efficient combination of chitosan and natural antimicrobial agents from carvacrol and grape seed extract applied as an active packaging in strawberries and salmon, presenting a significant log reduction on all microorganisms studied.

Wan et al. [109] highlighted the excellent antioxidant properties of chitosan-based films with high molecular weights and suggested the possible application of quaternized chitosan films in the food industry. Bonilla et al. [110] developed edible gelatin–chitosan-blended films containing boldo extract, which were applied to sliced Prato cheese, demonstrating that the films conferred significant protection against oxidation, inhibited the growth of psychrotrophic microorganisms, and slowed the development of coliforms in sliced Prato cheese samples.

2.1.6. Lipid-Based Biopolymer Packaging

The use of lipids in edible films and coatings has several advantages, including glossiness, moisture loss reduction, and inexpensive production costs [72,111]. Biopolymeric films produced from fats and oils are transparent and elastic, with enhanced moisture barrier properties due to their hydrophobic nature [72]. Natural waxes, vegetable oils (triglycerides), aceto-glycerides, and fatty acids are examples of lipids with a high potential for packaging applications [112]. Among them, waxes and glycerides are the most commonly utilized [113]. Bouaziz et al. [114] reported that dry, rubbery films can be synthesized from olive oil production waste (pomace) and low-quality olive oil (lampante) by a UV-based process.

Natural waxes are superior moisture barriers compared to other lipids because of their high concentration in long-chain fatty alcohols and alkanes. As such, waxes can be incorporated into biopolymer formulations to generate a water vapor barrier [115]. Biopolymer films with added wax have lower water vapor permeability and solubility, which are considered to be some of the most significant properties of suitable food packaging materials [116].

2.1.7. Biodegradable Foams

Foams made from conventional fossil-based polymers, such as expanded polystyrene (EPS) and polyurethane (PU), are frequently used in the food packaging sector. However, these polymers do not degrade naturally, and recycling them is not profitable, whereas foams produced from biodegradable polymers could be a promising solution to solve the disposal problem posed by petroleum-based polymeric foams [117–119]. Alongside starch, the most investigated biodegradable polymers for the development of biodegradable composite foams are polybutylene succinate (PBS), polycaprolactone (PCL), polylactic acid (PLA), and polyvinyl alcohol (PVOH) [117,118,120].

Several strategies, especially the formation of composites using additives, reinforcing fibers, fillers, or blending between materials, have been investigated to improve biodegradable foams' properties [118,120]. De Carvalho et al. [121] produced cassava-starch-based biodegradable foam trays coated with polyvinyl alcohol (PVOH) with a higher degree of hydrolysis. A decrease of approximately 50% in the water absorption capacity of the coated trays compared to the uncoated trays was observed. A biofoam based on cassava starch and containing grape stalks obtained through thermal expansion was used to pack English cake. The biofoam presented good biodegradability and flexural and mechanical properties and proved to be a promising alternative to EPS, which is currently used to pack foods with low moisture content [119]. Rodrigues et al. [122] reported the production of a biodegradable edible foam using a potato by-product with xanthan gum and natural oat fiber as reinforcement, presenting a low water absorption index. Rice husk ash can be a good filler in biodegradable cassava-starch-based foams, improving the thermal stability, density, and biodegradation and decreasing the water absorption capacity [123]. A biodegradability test on cassava-starch-based foams indicated over 50% biodegradation after 15 days [124]. The moisture barrier properties of sweet potato foams can be improved with the addition of oregano and thyme essential oils [125].

The use of inexpensive raw materials and additives, such as agri-food wastes, can significantly reduce the cost of producing biodegradable foams, which are more expensive than conventional foams.

2.2. Current Production Technologies

Traditional packaging contributes greatly to the logistics of food distribution, maintenance, preservation, and food safety, although some materials leave a gap in terms of sustainability. Researchers have promoted changes in the development of food packaging materials that focus on biodegradability, renewability, and reduced costs, meet the current food safety requirements, and reduce environmental impacts [126,127].

In recent years, techniques have been improved or developed to produce new packaging materials [128]. Each of them provides specific results in terms of structure and morphology. Other techniques are more appropriate for certain types of matrices, such as suspensions and polymeric composites. Some of them are briefly described below.

2.2.1. Solvent Casting

This technique is one of the oldest and most used for producing thermoplastic film samples [129]. It involves solubilization, casting, and drying and is still an attractive technique for preparing biopolymer-based biodegradable films [130,131]. With solvent casting, high-quality films from different polymer/solvent combinations can be prepared at a low cost and feature uniform thickness distribution, excellent flatness, dimensional stability, and high optical purity [129].

2.2.2. Tape Casting

The tape casting technique is well known in the paper, plastic, ceramic, and paint manufacturing industries; however, in recent years, this technique has been used to produce films based on biopolymers [132,133]. This method allows the spreading of a suspension on large supports, with the thickness being controlled by a blade adjustment at the bottom of the spreading device. Under controlled conditions, the film can be dried on the support itself. The formed film is dried on the support by heat conduction, hot air circulation, and infrared, resulting in a reduction of its thickness [134].

2.2.3. Melt Extrusion

Extrusion processing is a commonly used process in the global agri-food processing industry, particularly in the food and feed sectors, with several applications [135,136]. In recent years, this technique has been improved to manufacture biodegradable active packaging, mainly by producing films with good thermal stability and acceptable mechanical properties [135,137]. This process combines several unit operations, including mixing, baking, kneading, shearing, molding, and forming [138]. According to García-Guzmán et al. [139], melt extrusion favored the development of nanostructured materials with nanofibers, nanoparticles, and high-value compounds to develop smart packaging.

2.2.4. Thermopressing/Thermoforming

Thermoforming involves heating and pressurizing a plasticized polymer resin mixture to obtain a viscoelastic material, shaping it into a mold, and trimming it to create the final package or container or forming a film when cooled [24]. According to Gómez-Estaca et al. [140], with this technology, it is possible to obtain films or containers such as pots and trays and produce adherent multilayer materials that can be of great interest in various applications for food packaging. Furthermore, in recent decades, several biodegradable materials have been developed or improved to be suitable for thermoforming processing [141,142].

2.2.5. Compression Molding

Compression molding is one of the oldest material processing techniques. For plastics, it was one of the first industrial methods and is also known as pressure molding [143]. In this method, the molding is preheated. Then, the polymer material is placed in an open, heated mold cavity. Under high pressure, the material adapts to all areas of the mold until it cures under constant heat and pressure [144]. This technique has been used singly or combined with other techniques to produce biodegradable films, such as intensive mixing or melt extrusion [145,146].

2.2.6. Layer-By-Layer (LBL) Assembly

The layer-by-layer electrostatic deposition (LBL) technique is a versatile way to manufacture multicomponent films that generally do not require sophisticated instruments, and the films formed are independent of the shape of the substrate [147,148]. This technique has been extensively explored in biomaterial films. An advantage of LBL assembly is that it can be combined with other conventional techniques, distinguishing its ability to manufacture functional materials with excellent barrier and separation properties even in extreme humidity conditions [135].

2.2.7. Electrospinning/Electrospraying

The electrospinning technique is a simple, efficient, and low-cost technique capable of manufacturing non-woven fibers, usually in submicrometric or nanoscale diameters [149,150]. This technique has variations such as electrospraying, which, in the field of food processing, is used in the production of micro- and nanoparticles, food coating, and film formation [151]. According to Zhao et al. [152] and Aman Mohammadi et al. [128], electrospun materials are good candidates to produce food packaging with characteristics of smart packaging, although their application on an industrial scale is still limited. Furthermore, electrospraying has solved problems such as a lack of uniformity in thickness and homogeneity related to techniques such as casting and coextrusion. Gaona-Sanchez et al. [53] reported that this technique effectively produced zein films without the deficiencies associated with conventional production methods.

3. The Business of the Sustainable Food Packaging

3.1. Biorefinery Model of Agri-Food Waste and Contribution to Bioeconomy

A biorefinery is an industrial concept that aims to produce a wide range of products from one biomass. If no waste is generated, then it will be sustainable biorefinery. This technique allows for the maximization of the value of the biomass feedstock, as different intermediates and products can be produced while preventing resource loss and environmental impacts [153]. The biorefinery approach can be efficiently applied to produce green, low-cost, and value-added products from commonly available agri-food waste [154].

Over the past few decades, many efforts have been made in regard to the valorization of agro-industrial by-products, and the implementation of biorefineries is considered a promising concept to valorize these materials [155]. The conversion of agri-food wastes and by-products into new products makes the process more sustainable, in addition to developing a circular bioeconomy principle [156]. Numerous products such as cellulose, bioplastics, pigments, and biofuels can be obtained simultaneously from the same agri-food waste [157]. Figure 3 summarizes the valorization pathways of several agri-food waste and by-product categories, showing some biomaterials obtained with potential applications in the development of food packaging. The data were obtained from cross-research between the keywords (agri-food waste/by-product AND biomaterial) via the Web of Science database. From the available literature and the interrelations shown by the Sankey diagram (Figure 3) between bioproducts production from agri-food waste and by-products, 27,395 articles were published in the "bagasse, pomace, pulp" group, with 23,172 articles in the "bran, cobs, meal and straw" group and 28,171 in the "peels, hulls, husks and shell" group. The polysaccharides cellulose and hemicellulose, primarily the first, presented higher flow rates. This conclusion corroborates the results of several studies reported by Panyasiri et al. [158], Saelee et al. [159], Espinosa et al. [160], and Hideno et al. [161], who obtained nanocellulose from cassava bagasse, sugarcane bagasse, wheat straw, and orange peels, respectively. This can be explained by the lignocellulosic characteristics of the recovered biomass. On the other hand, the agri-food wastes group formed by roots, stalks, and stems had the highest number of published articles (around 42,470). In this case, the flow rate was divided between obtaining starch, pigments, phenolic compounds, and cellulose, as reported by Zhang et al. [162], Repajić et al. [163], Ngoc et al. [164], and Lima et al. [165], who obtained starch from the root tubers of *Stephania Epigaea*, pigments from wild nettle (*Urtica dioica* L.) stalks, phenolic compounds from *Fissistigma polyanthoides* stems, and cellulose nanofibers from the roots and stems of *Salicornia ramosissima*, respectively.

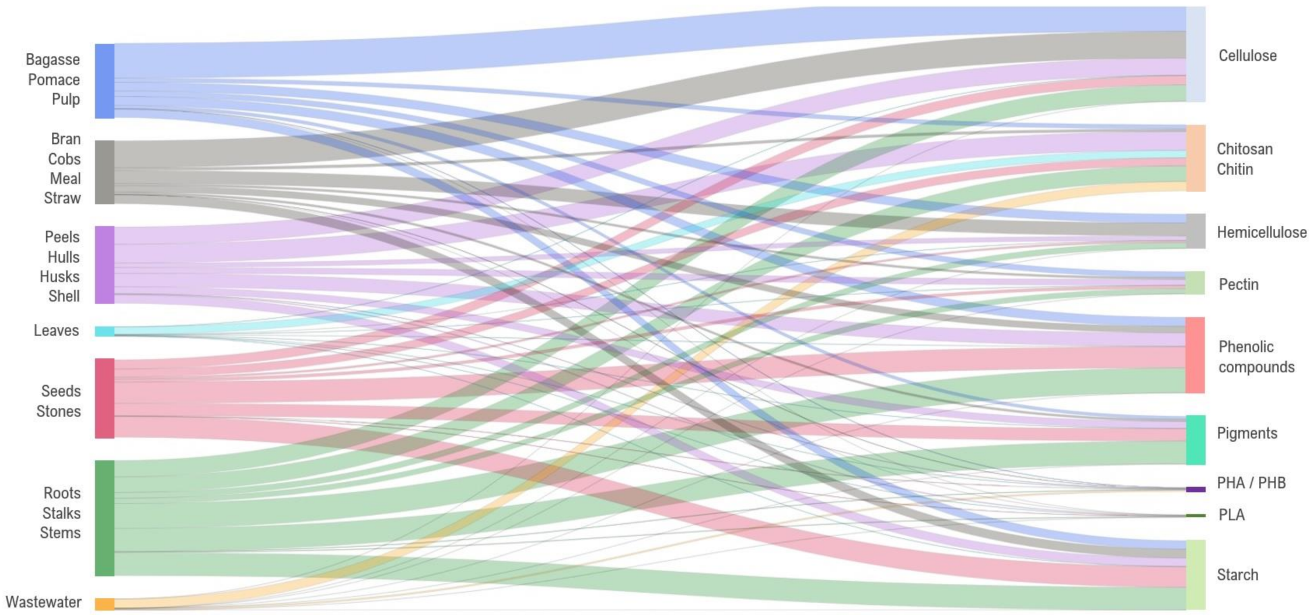

Figure 3. Sankey diagram depicting the valorization pathways of agri-food waste and by-products and respective value-added bioproducts with potential application in the food packaging industry.

Many agri-food by-products have been used in the production of bioplastics, as they are an interesting source of biopolymers, such as cellulose, polylactides, and polyhydroxyalkanoates (PHAs) [166]. The implementation of biorefinery platforms from by-products to produce bioplastics would be beneficial to waste disposal and management, reducing greenhouse gas emissions [166]. The integration of fuel/energy with bioplastic production can reduce energy needs, reduce the high production costs, and consequently minimize negative environmental impacts and improve economic perspectives [167–169].

The biorefinery concept contributes to the development of circular bioeconomy principles to promote a closed-loop sustainable framework by enhancing the reuse, recovery, and recycling of by-products [170,171]. The process design for the biorefinery conception needs to evaluate its economic feasibility and environmental sustainability, in which a wide range of end-products that satisfy different markets corroborate with the circular bioeconomy model [172]. The EU Bioeconomy Strategy's action plan established a goal to develop 300 new sustainable biorefineries by 2030, ensuring the high circularity and resource efficiency of the biological resources [173].

Research by the European Commission JRC's "Biorefineries distribution in the EU" reported 177 integrated biorefineries that combine the production of bio-based products and energy [174]. Integrated biorefineries have emerged as a suitable value-added approach to existing challenges. Thus, the combination of low-value, high-volume products and low-volume, high-value products is a great production strategy for business feasibility [175]. A techno-economic analysis of a mango waste biorefinery was reported by [176], showing a profitability improvement in regard to the co-production of pectin and bioenergy and identifying the feedstock cost as the main contribution to the annual operating cost, representing more than 90% of the total variable costs. Another study [177] reported that the mango-waste- (seeds and peels) integrated biorefinery operating within 120 days was economically attractive at capacities above 5 tons per hour.

The study by [178] analyzed the technical viability of different scenarios for lactic acid production from food waste, showing that the integrated biorefineries and upscaled designs are economically more attractive and allow the transformation from a linear to a circular bioeconomy. Ortiz-Sanchez et al. [179] evaluated the production of pectin, essential oils, and biogas as an alternative to valorize orange peel waste and identified the utility cost as the most representative cost in the process, where the plant capacity should scale up to be profitable. Thus, the economic performance of biorefineries is affected by the different pathways implemented by the industry, and the profitability can be greatly dependent on the size of the biorefineries and market prices [180].

Bioplastic biorefineries have been documented in limited case studies, and several studies focused on extraction methods and biofuel/bioenergy production from agri-food waste.

3.1.1. Case Studies on Spent Coffee Grounds (SCGs)

Coffee is the second internationally traded commodity, with a global daily consumption of 2.25 billion cups [181]. The popularity of the beverage is responsible for the production of a large amount of spent coffee grounds, which is estimated to be 6 million tons worldwide, in which 1 ton generates about 650 kg of SCGs [182,183]. Most of the SCGs produced are disposed of in landfills or, in some cases, used as an energy source due to their high calorific power [184]. However, a great variety of SCG value-added compounds are underutilized, such as bioethanol, bioplastics, and chemicals. Obruca et al. [39] investigated a SCG biorefinery for the obtention of PHB and carotenoids using coffee oil extracted from SCG as a substrate, resulting in high productivity (90.1 and 89.1%; $Y_{P/S}$ = 0.88 and 0.82 g/g). Furthermore, the solid residue was used as a feedstock for the synthesis of PHB, achieving 56.0 and 51.1% ($Y_{P/S}$ = 0.24 and 0.04 g/g). In another study, [185] correlated the high content of free fatty acids (FFA) in coffee oil to a positive factor in PHB accumulation, in which the production of PHB from SCGs and the co-generation of energy might significantly reduce the production cost of PHB. SCG biorefineries were also studied by [185] assessing four scenarios in terms of their economic and environmental performances, evaluating the production of biodiesel and electricity (Scenario B and C) and the biodiesel with a range of high-value chemicals, including PHB bioplastic (Scenario A and D). Generally, the largest costs in Scenarios A and D were attributed to oil extraction and PHB production, and the production of high-value products alongside biofuel can reduce the biofuel production cost [186]. In the last scenario, the biodiesel production cost decreased by 4% from 0.72 to 0.69 £/L, significantly improving the net present value and leading to a reduced economic risk due to the even distribution of annual revenue across many products. However, the environmental impact is directly affected by energy consumption since the study did not involve on-site energy recovery via combustion, resulting in higher net electricity and heat consumption.

3.1.2. Case Studies on Banana-Biomass-Based Refineries

Rejected bananas can reach up to 30% of the total production, which is an important source of high-value compounds [187]. The valorization of these materials in a biorefinery concept can convert the substrates into fuels, chemicals, and biopolymers, which is beneficial to the environment and economy, as reported by [157]. Generally, banana by-products are a lignocellulosic source that is rich in cellulose (28.92%), hemicellulose (25.23%), and lignin (19.56%) that can be converted into biofuels and other valuable chemicals [188]. It was demonstrated that 1 kg of raw banana stem material produced 0.259 kg of ethanol [189]; additionally, the yields of bioethanol production from banana pseudostems and rachis were about 87 and 74%, respectively [190]. Moreover, banana leaves are a source of lignocellulosic micro/nanofibers (LCMNF) that can be used as mechanical reinforcement, yielding up to 82.44% [191], and banana peel residues were reported as feedstock to produce PHA, PHB, and PLA [192–194]. The biorefinery concept was analyzed for the production of PHB, glucose, and ethanol from banana peels and pulp [169]. A production cost of 2.7 USD/kg was reported when PHB was a unique product, and banana peels were treated as residue (Scenario 1). This value decreased to 2.3 USD/kg when PHB, glucose, and ethanol were produced in a biorefinery (Scenario 2), and 1.6 USD/kg was achieved, considering the mass and energy integration of the processes (Scenario 3). Additionally, by analyzing different scenarios, it is possible to note a huge difference in the economic margin of PHB with 22/43/106% by comparing the market prices of the studied products. This report also highlights a reduction in energy and water requirements by 30.6 and 35%, respectively, when an integrated biorefinery is adopted.

3.2. Market Opportunities

Currently, there has been an increase in the publications in the literature related to agri-food waste re-usage, showing a wide potential for high-benefit products with high economical value. Thus, there is an increasing interest in agri-food by-products as a source of bio-based materials with potential use in the packaging industry. The global food packaging market was valued at USD 346.5 billion in 2021, and the bioplastic market is predicted to reach USD 2.87 million in 2025, with a 36% growth from 2020 [195,196]. Moreover, the largest bioplastic producers in 2022 are mostly focused in Asia, with Asia encompassing more than 41% of the production, whereas Europe only encompasses 26.5% of the production, North America encompasses 18.9%, and South America encompasses 12.6% [195].

Bio-based materials from agri-food wastes are considered a potential solution to a growing market of bioplastic packaging, with several benefits regarding environmental impacts. The use of renewable sources contributes to the sustainability aspects over the whole life cycle of the materials. The bio-based material market is mainly composed of starch fiber, cellulose fiber, polysaccharides, chitosan, PLA, PHB, and PHA, and other materials could be used as bioactive ingredients (Table 2).

Table 2. Bio-based material global market size.

Bio-Based Material	Market Size (USD) (Year)	Reference
Starch fiber	97.85 Bn (2020)	[197]
Cellulose fiber	35.20 Bn (2021)	[198]
Pigment	34 Bn (2020)	[199]
Polysaccharide	12.2 Bn (2018)	[200]
Antimicrobial coating	9 Bn (2021)	[201]
Chitosan	6.8 Bn (2019)	[202]
Antioxidant	3.92 Bn (2020)	[203]
Pectin	944.45 Mn (2021)	[204]
Polylactic Acid (PLA)	698.200 Mn (2020)	[205]
Nanocellulose	291.53 Mn (2019)	[206]
Poly-3-Hydroxybutyrate (PHB)	102.4 Mn (2021)	[207]
Polyhydroxyalkanoates (PHA)	85 Mn (2021)	[208]

Bioplastics have a great growth opportunity in the global market, which is set to increase from 2.23 million tons in 2022 to 6.3 million tons in 2027. Food packaging remains the largest field of applications, encompassing 48% of the total bioplastics market in 2022 [195]. The global cellulose fiber market may reach over USD 60.01 billion by 2028 [198], and the production of nanocellulose has become intensively investigated worldwide, with the pilot and industrial production lines mainly located in developed countries. CellForce [209] in Canada built up a CNC pilot production to prepare 300 tons per year, while American Process produces 1000 kg/d of CNF [195]. However, only a few companies, such as VTT [210], developed a CNF-based plastic film for food packaging from the side streams of a food manufacturing process material in pilot lines.

According to the latest market data compiled by European Bioplastic [195], in 2022, biodegradable plastics represented more than 51% of the global production of bioplastics, of which PLA represented 20.7% and is estimated to reach 37.9% in 2027. Considering the PLA production chain, the raw materials substrate and fermentation processes and lactic acid production cover approximately 40–70% of production costs [211]. The final price is influenced by the application and is reaching 4.6 USD/kg nowadays, generally following the price of the feedstocks used for fermentation [212]. A study reported a minimum selling price for lactic acid at 0.56 USD/kg when pre-treated corn stover was used as a substrate; therefore, the use of renewable and low-cost materials allows a more economically competitive process [213,214].

Since eco-friendly packaging has been growing in market size, companies are interested in making it less expensive. The PLA market size is expected to increase by 26.6% from 2022 to 2030, with packaging accounting for over 36% of the revenue [215]. The main players in the global market include Total Corbion, NatureWorks, Supla, Futerro, and Cofco, with different technological strategies for the production of PLA [216]. NatureWorks has technology that can use greenhouse gases as feedstock instead of materials derived from plants; Corbion is actively exploring the use of second- and third-generation feedstock, including food waste and industrial waste streams; and Futerro set up a new integrated biorefinery in Europe to produce and recycle PLA [217–219].

Similar to PLA bioplastic production, PHA requires a high cost for the raw materials (about 30–40% of the total production costs), which has been reported at 2.6 USD/kg when using sucrose as a carbon source, with a payback period of 2.9 years and a return on investment of 34.2% [220]. The process can become more economically competitive for an industrial plant when the carbon source is replaced by sugarcane bagasse to produce P3HB, as observed by [220]. This concept has been successfully adopted by some companies, as Bio-on used molasses and by-products of sugar beet production as raw materials for PHB production [221]. Food waste destined for landfills has been used by Genecis and Full Cycle as raw materials to produce biodegradable plastics and other high-value materials [222,223].

Companies have begun experimenting with bioplastic solutions, with an ever-increasing number of big brands releasing their first large-scale products. [224]. The connection between industries and universities allows for the development of different biotechnology processes, in which agri-food by-products have been shown to be promising raw materials [225]. There has been an increase of bioplastics on the market, as well as diversified materials, products, and applications, which have helped make bioplastics an attractive choice that is well-accepted by consumers.

4. Sustainable Prospects

4.1. The Turning Point of the Food Packaging Industry

Today, sustainability is no longer a trend and has become a concern inserted into the habits of consumers, especially younger ones. Therefore, companies that do not seek to promote changes with a positive impact on sustainable development will have difficulties in attracting and retaining consumers, retaining employees, and attracting investors.

Modern food packaging contributes to food preservation, safety, and stability and makes product transportation more efficient by reducing food and resource waste [226]. According to Shin and Selke [227], more than two-thirds of all materials used to manufacture packaging materials, such as paper, plastic, and glass, are used by the food sector. However, although food packaging represents the fastest-growing sector in the field of synthetic packaging, most of this packaging is designed for a single use and is not reused or recycled [228].

The challenges of the packaging industry to achieve sustainability are many and go beyond the search for innovations aimed at increasing the packaged product quality, extending shelf life, and reducing food waste. On the other hand, the packaging industry has been striving to find new bio-based materials that optimize the performance and the use of packaging [229]. In this sense, Peelman et al. [230] proposed a simple redesign divided into three levels as an alternative for the packaging industry to reach full sustainability, which is shown in Figure 4.

According to the United States Environmental Protection Agency (EPA), food waste and food packaging represent about half of all solid waste [231]. A survey by EUROSTAT [232] revealed alarming data stating that in the European Union, each resident generates around 200 kg of packaging waste annually. Among the most common packaging wastes in the EU, paper and cardboard account for 41.5%, followed by plastic (19.5%) and glass (19.1%) [232]. Taking this into account, EU is proposing an update of the current

Directive on Packaging and Packaging Waste, aiming to make all packaging fully recyclable by 2030, reducing the negative environmental impacts and being in accordance with the European Green Deal and the new Circular Economy Action Plan [233].

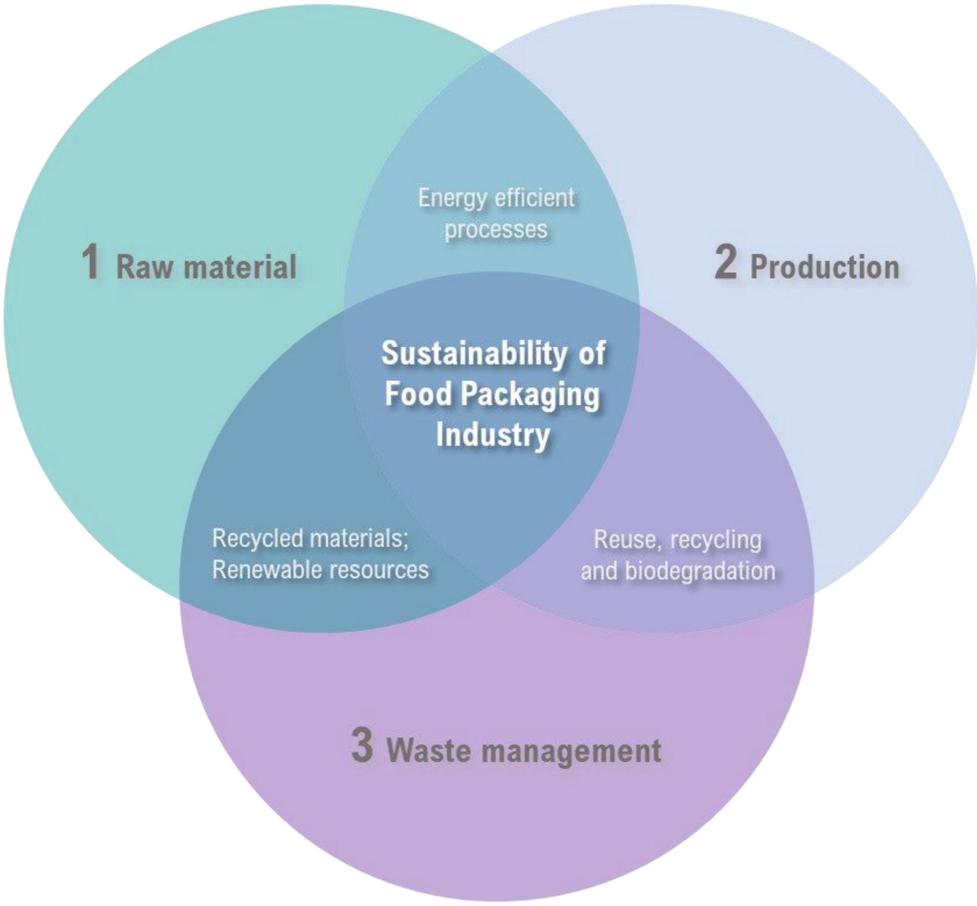

Figure 4. Venn diagram exemplifying how the sustainability of food packaging can be achieved from three levels.

Furthermore, in the year 2020, the total volume of packaging waste generated in the EU was estimated at 79.3 million tons, an increase of around 25% compared to the beginning of the decade [232]. On the other hand, recovering and recycling packaging waste has not kept up with the accelerated growth of the sector, largely due to changes in food preparation and consumption habits. Furthermore, the low adherence by industries to eco-friendly solutions to waste management and the adoption of a circular economy model perpetuates outdated systems to the end of the life cycle of food packaging, such as incinerators, landfills, and disposal in the environment [234–236].

4.2. The Scientific Approach to the Sustainable Food Packaging

Technological development and innovation in the sustainable packaging sector are in their maturation period, confirming that this is an opportune moment to invest resources and intellectual activity in research in this sector. In this sense, an investigation on the Web of Science platform with access to several databases provided us with information on the number of surveys related to sustainable food packaging between 2002 and 2022, highlighting the academic and commercial potential of this work. The investigation considered original articles and review articles as a type of document (Figure 5).

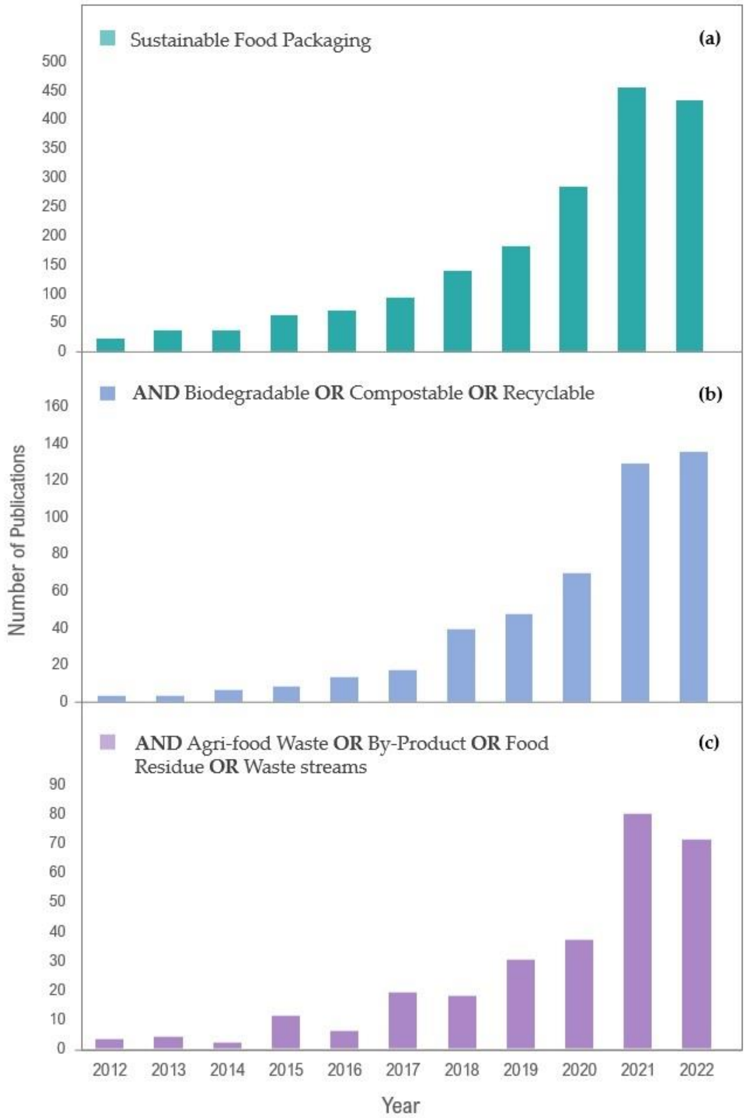

Figure 5. Number of publications in the last 10 years related to (**a**) sustainable food packaging, focused on (**b**) biodegradable, compostable and recycled materials, and (**c**) through the use of recovery of agri-food waste, by-products, food residues and waste streams (from 2012 to 2022). Source: the authors, based on data presented on the website (http://www.webofscience.com (accessed on 26 January 2023)).

As can be seen in Figure 5a, publications related to the main topic that had "Sustainable food packaging" as a keyword increased from 31 in 2012 to 431 publications in 2022, an increase of almost twenty times in ten years. When refining the search by adding subtopics with the keywords "Biodegradable OR Compostable OR Recyclable", a total of 135 publications were found in 2022 (Figure 5b), indicating an interest that was 45 times higher compared to 2012. In the same way, when adding the keywords "Agri-food Waste OR By-Product OR Food Residue OR Waste streams" (Figure 5c) as subtopics, the number of publications increased steadily from 3 at the beginning of the decade to 71 in 2022.

This growth trend in publications shows that sustainability in the food packaging sector is a topic that is still in an early stage; however, there is potential for the scientific and technological development of new methods of producing biomaterials from renewable sources that meet the challenges of Agenda 2030 for Sustainable Development Goals, namely goal no. 12 about "Responsible consumption and production" [237].

Another important fact concerns the growing number of patents related to the production of biodegradable materials for food packaging, as well as the development of methods for the composting, recycling, and reuse of packaging, as shown in Figure 6. Data from the European Patent Office (EPO), using the keywords "Biodegradable OR Compostable OR Recyclable OR Reusable" all followed by the suffix "Food Packaging", showed that the increase in the number of patents is a response to the high market value that this type of material has for the industry.

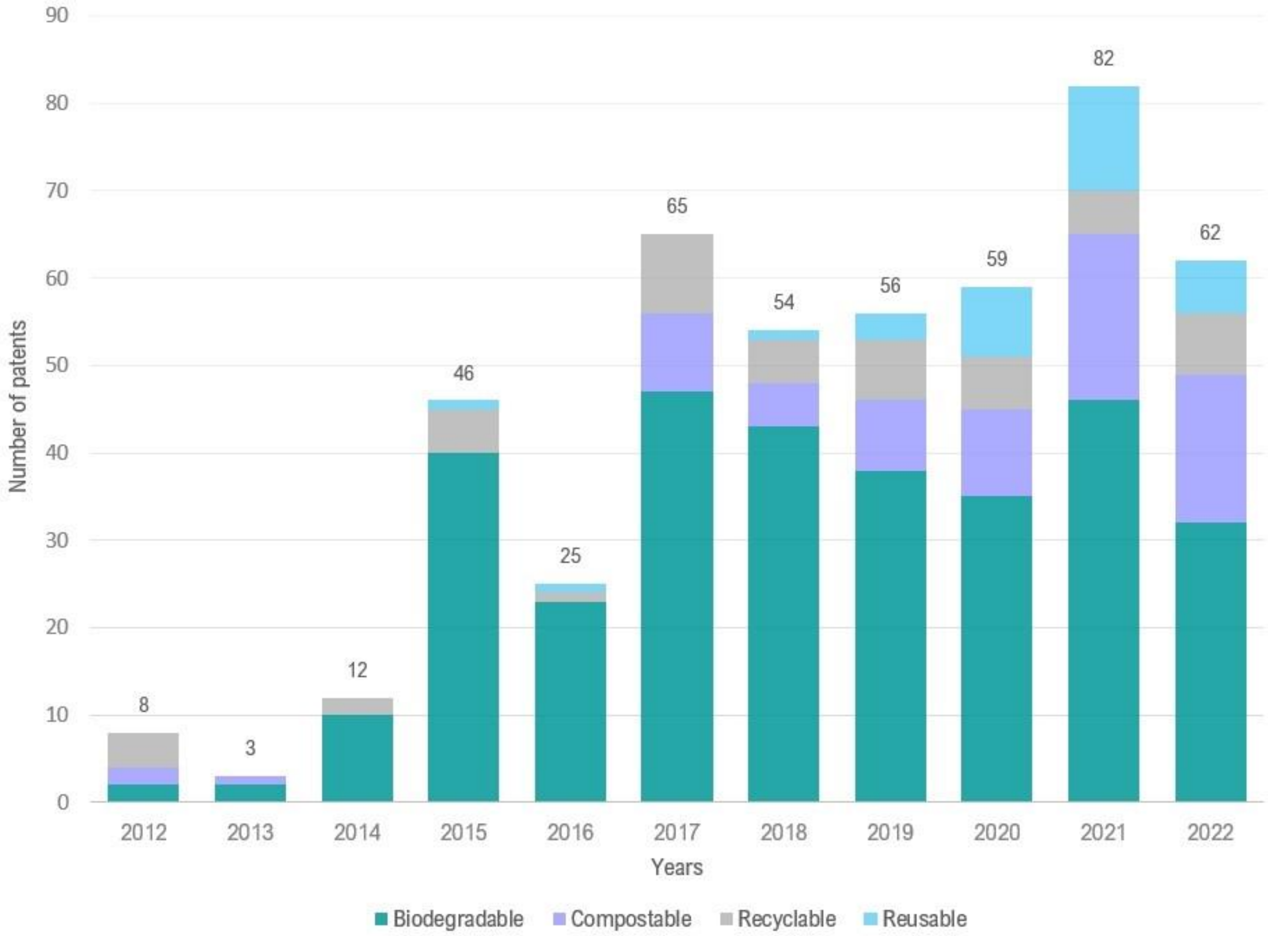

Figure 6. Patent publications over the years (2012–2022) related to Sustainable Food Packaging (biodegradable, compostable, recyclable, reusable). Source: the authors, based on data presented by European Patent Officer from the Espacenet Patent Search (https://worldwide.espacenet.com/patent (accessed on 28 January 2023)).

Patents related to "biodegradable food packaging" increased from 2 in 2012 to 32 in 2022, reaching almost 50 in previous years such as 2017 and 2021. For "compostable food packaging", the increase was gradual, with the number of patents in 2022 being 8 times higher than that registered 10 years earlier. As for recyclable and/or reusable food packaging, the number of patents doubled in a decade.

It is important to differentiate between biodegradable and compostable. Although in a broader context, they seem like similar terms, technically, they do not represent the same thing and can easily be confused. While all compostable material is biodegradable, not all biodegradable material is compostable. According to the American Society for Testing and Materials (ASTM), biodegradable means anything that undergoes degradation resulting from the action of naturally occurring microorganisms, such as bacteria, fungi, and algae, that does not occur after a defined time but does occur quicker than for non-biodegradable products. By contrast, compostable materials generally decompose in 90 days through biological processes during composting, that is, in controlled conditions where CO_2, water, inorganic compounds, and biomass are produced at a rate that is consistent with other compostable materials and leave no visible, distinguishable, or toxic residue [238–240]. In summary, compostable materials are biodegradable and present valuable nutrients for the environment because of decomposition.

4.3. Sustainable Strategies of the Food Packaging Chain

In recent years, studies indicate changes in consumer behavior regarding willingness to investigate which companies have integrated sustainability into their business models. This criterion has become an important factor in decision-making on whether or not to buy a product from a company [241–243]. In this sense, data from a recent poll by the United Nations Development Program, in partnership with the sociology department at the University of Oxford, showed that about two-thirds of respondents believe that the impacts of climate change in the long term require urgent measures from the world. This consumer awareness has been reflected in the behavior of companies and has increased the demand for corporate responsibility [244].

According to the conclusions of an Ipsos poll carried out in September 2020 [243], more than 60% of Americans adults said they believe that buying sustainable brands or products is an environmentally friendly attitude, and more than 50% said they feel “better” when consuming sustainable products.

Because of these changes in consumption habits or due to government and shareholder pressure, many food companies have increased their level of social responsibility and integrated sustainability into their business models and marketing strategies. Moreover, many companies have invested heavily in innovation for the development of sustainable packaging using alternative materials or even in circular economy models to mitigate the environmental impacts of the food packaging sector. Table 3 shows some actions and strategies of some of the most relevant global companies to make the packaging sector more circular and sustainable.

Table 3. Actions and strategies of global companies to sustainable packaging.

Company	Packaging Strategy	Sustainable Action	Reference
Coca-Cola	Clear PET	Transition from green to clear polyethylene terephthalate (PET)	[245]
McDonald’s and Costa Coffee	Paper cups	On-the-go cup recycling scheme	[246]
Danone	PET and rPET cups	Replace the packaging from PS (polystyrene) to PET	[247]
PepsiCo	100% recycled or renewable plastic	Eliminate the use of virgin fossil-based plastics in the crisp packets	[248]
Unilever (Carte D’Or)	Paper tubs and lids	Transition of the ice cream packaging from plastic to paper tubs and lids	[249]
Kraft Heinz (Kraft Mac & Cheese)	Recyclable fiber-based microwavable cup	Replace non-recyclable plastic cups	[250]
Kraft Heinz (Shake ’N Bake)	Reusable container	Removal of the plastic “shaker” bag from its products	[251]
Mondelez	Recyclable packaging	Replace all non-recyclable packaging to packaging from 100% recyclable material.	[252]
Nestlé	Sustainable packaging solutions	Accelerate the development of sustainable packaging solutions	[253]
Tesco	Reusable and refillable packaging	Tesco’s 4Rs packaging strategy (Remove, Reduce, Reuse, Recycle)	[254]
Starbucks	Recyclable strawless lid and paper or compostable plastic straw	Eliminate single-use plastic straws and develop alternative-material straw	[255]
Bacardi	Recyclable plastic	Replacing Non-Refillable Fitment (NRF) plastic commonplace throughout the spirits industry with	[256]

Several companies have made high investments in sustainability strategies. This is the case for Nestlé, which invested around $2.5 billion in programs to accelerate the development of sustainable packaging solutions [253] in which an amount goes toward investing in start-ups focused on recycling solutions, refill systems, and new packaging materials. All these initiatives aim to achieve, by 2025, targets such as reducing the use of virgin plastics, promoting the circular economy, eliminating plastic waste from the marine environment, and the complete transition to recyclable or reusable packaging.

Recognizing that waste generation from packaging is an important and urgent issue, the Coca-Cola Company announced in 2019 the transition from the traditional Sprite soft drink green PET bottle to transparent PET [245]. With this change, the company hopes to contribute to the acceleration of the circular economy for PET bottles, where according to studies by GA Circular, a circular economy action and advisory company, the change to transparent PET has a higher after-use market value and higher recyclability [257]. Thus, Coca-Cola aims to contribute with its goal of collecting and recycling 100% of its packaging.

In the same way, Danone created the "Danone Packaging Transformation Accelerator" to foster innovation and development in its packaging sector. According to data presented in the Global Commitment 2021 Signatory Report [247], the company has a budget of more than USD 1.100 million for promoting packaging transformation and redesign projects, transitioning from PS packaging to PET and rPET, eliminating the use of PVC, optimizing of collecting systems, and integrating recycled content.

From a business perspective, it is evident that sustainability has been seen as a strategy to generate competitive advantage to create economic value and positive social and environmental impacts. Considering the finite nature of resources and the necessity to ensure their sustainability for the next generations, food packaging companies and other sectors have concluded that changing actions and habits may be the only way to adapt economic growth to a future with limited resources. Sustainability principles are the best way to meet the demand for sustainable products and comply with increasingly strict environmental laws.

4.4. LCA as a Tool for the Food Packaging Industry

Life cycle assessment (LCA) is a powerful tool to identify, quantify, and assess the sources of environmental impact related to a product, from raw material acquisition to production, distribution, use, and disposal [258]. Following the requirements and guidelines of ISO 14044, such as the definition of objective and scope, the analysis of the life cycle inventory, the evaluation and interpretation phases, as well as the limitations of the study and the critical review [259], this tool can be used by the packaging industry to compare the environmental impact and costs of different packaging products and determine which is the best option [260–262]. Thus, in addition to promoting improvements in packaging development, LCA can increase a company's degree of sustainability and corporate image, support marketing claims, and even identify appropriate performance indicators. In lab-scale studies, the implementation of LCA should be considered the raw material resource and extraction method to reduce environmental impacts before the scale-up process [263].

Table 4 shows some research on the implementation of LCA directed to biorefineries based on the valorization of residues and by-products as renewable raw materials to obtain a range of biologically based products and bioenergy through sustainable biotechnological routes. These integrated approaches incorporate multi-step bioprocesses that exploit waste streams and biomass feedstock, often with low added value to produce bioproducts with potential application in the sustainable packaging industry and maximize productivity and improve environmental performance [32,264,265].

Table 4. LCA studies aimed at biorefineries based on waste and by-products recovery as renewable raw materials.

Raw Material	Bioproduct	LCA	Reference
Agro-industrial by-products and marine residues	Polymers	LCA of bio-based films. Identifying the most pollutant phases of the life cycle for biofilms from different resources	[266]

Table 4. *Cont.*

Raw Material	Bioproduct	LCA	Reference
Orange peel-derived pectin jelly and corn starch	Pectin	LCA as a cradle-to-gate model. Biodegradation performance compared to a LDPE film	[267]
Dunaliella salina microalga and carrot (Daucus carota)	β-carotene	LCA of extraction methods (solvent, microwave, and ultrasound)	[268]
Spirulina platensis	Phycocyanin	LCA of extraction methods (solvent extraction and ultrasound)	[269]
Microalgae	Pigments, biodiesel	LCA and TEA * of three biorefinery routes	[270]
Packaging	Starch and PHA	LCA of biodegradable and conventional plastic packaging	[271]
Food waste valorization (bread, rice, and fruit waste)	Hydroxymethylfurfural (HMF)	LCA of different solvents to evaluate the environmental performance	[272]
Red wine pomace	Polyphenol	TEA and LCA of solvent extraction and pressurized liquid extraction	[273]
Vine shoots	Oligosaccharides	LCA to identify the most sustainable biorefining route	[274]
Sugar beet pulp	Oligosaccharides	LCA to analyze different extraction	[275]
Onion waste	Quercetin and frutooligosaccharides	LCA of solvent extraction	[276]
Rosemary leaves	Antioxidants	LCA of supercritical extraction and water extraction, particle formation on-line process (WEPO) and pressurized hot water extraction	[277]
Carrot waste	Cellulose nanofiber	LCA to evaluate production process	[278]
Coconut waste	Cellulose nanocrystal	LCA of extraction methods	[279]
Chicory grounds	Polyphenol	LCA of extraction methods	[280]
Olive mill wastewater	Phenolic compounds	LCA and CBA ** of process	[281]
Citrus waste	Pectin	LCA of extraction methods (solvent and microwave)	[282]
Microalgal cultivation	Value-added products	Enviro-economical assessment of microalgal production	[283]

* TEA—Techno Economic Assessment; ** CBA—Cost–benefit analysis.

Overall, LCA helps prioritize process and product improvements. In the studies presented in Table 4, LCA, TEA, and CBA were some of the methodologies applied to optimize extraction methods and production processes or optimize sustainable routes for biorefineries. Regarding food packaging, it is decisive to consider factors such as obtaining or supplying raw materials that cover all packaging components; packaging use, including the entire supply chain from the factory to the end user; and the packaging disposal after use, known as the end-of-life of packaging. In this sense, finding environmentally sustainable alternatives must be applied to methods and tools to estimate and identify the packaging's environmental impacts throughout its life [284].

Recent examples show the success of the LCA as a tool for mitigating environmental impacts. In 2020, Tetra Pak performed a LCA on its carton packs and compared the environmental performance of several alternative packaging systems for beverages and food in the European market. They found that carton packs that use renewable materials in their multilayers, such as plant-based plastic, have a low carbon footprint (total greenhouse gas emissions directly and indirectly caused by an activity or product, expressed in CO_2 equivalent) and a lower climate impact [285]. IVL Swedish Environmental Research carried out LCAs on paper packaging from Billerud (Packaging and Containers Manufacturing, Sweden) and compared the performance of their paper packaging with corresponding solutions made with other materials, considering the entire product life cycle. As a result, they found that paper bags had up to 50% less carbon dioxide emissions compared to recycled paper bags, bio-based plastic bags, and recycled plastic bags [286].

Despite proving to be a successful tool for estimating and identifying the environmental impacts associated with packaging throughout its life cycle, the LCA analysis has limitations that need to be optimized. Some studies indicate that the methodologies used in LCA are not consensual, with disparities and uncertainties that lead to results that are not transparent, incomparable, and misleading [287–289]. According to Omolayo et al. [289], the current policy for the prevention, management, and recovery of food waste and packaging is not considered in the LCA analysis of waste and food by-products. In other words, the potential of handling waste for the development of packaging is dependent on factors inherent to each region, such as the existence of appropriate facilities for management, recovery, and recycling and the seasonality of products that generate waste.

Efforts are being made to explore and optimize waste recovery technologies to increase the sustainability of the packaging industry through LCA analysis. Therefore, in a future perspective, LCA researchers are encouraged to increase the reliability, repeatability, and representativeness of LCA results through comprehensive modeling studies and critical point sensitivity analyses that consider distinct systems. Finally, global promotion of the development of packaging using agri-food wastes and by-products will likely increase the integrity and quality of LCA results.

5. Final Remarks

Some issues involving the recovery of agri-food waste and by-products are crucial to the sector's development. Some biorefineries cannot work with large feedstock volumes due to the seasonality of some products. It is also important to note that there are no studies that indicate the best way to centralize waste management. Biorefineries may not want to pay for logistics if the logistical costs exceed the added value of biomass. Therefore, the agroindustry chooses to decompose waste in incinerators or landfills. By implementing a circular bioeconomy model, food waste and by-products, as well as biomaterials developed by biorefineries, can be revalued, thereby reducing these problems.

The current methods of processing and producing some biomaterials from food waste and by-products on a laboratory scale indicate a low yield. To make bioproducts more viable for large-scale production and commercialization, these results need to be improved. The most common ways to achieve better yields are concentrated on improvements in processing and production techniques. A possible way to financially overcome the lower yield is through the integration of production in a multi-feedstock biorefinery model from the same bioproduct.

The growth trend of studies related to the production of sustainable packaging from agri-food waste and by-products highlights the potential of this sector. In spite of some pointed difficulties, biodegradable, compostable, or reusable food packaging production can provide packaging that is suitable for sustainable development and made from renewable resources.

Author Contributions: Conceptualization, N.L.C., A.R.L. and M.C.V.; writing—original draft preparation, N.L.C., A.R.L., R.D.N.T., A.C.Q. and M.C.V.; writing—review and editing, N.L.C., A.R.L. and M.C.V.; supervision, M.C.V.; funding acquisition, M.C.V. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Funds through Foundation for Science and Technology (FCT) under the Project UIDB/05183/2020. N.L.C. and A.R.L. are supported by national funds through FCT PhD grants (SFRH/BD/149395/2019) and (SFRH/BD/149398/2019), respectively. R.D.N.T. and A.C.Q. are supported by European Union's Horizon funds through FunTomP project (PRIMA/2032/2021), which is part of the Partnership on Research and Innovation in the Mediterranean Area (PRIMA) program.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

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

References

1. FAO Food Waste Footprint: Impacts on Natural Resources. 2013. Available online: https://www.fao.org/sustainable-food-value-chains/library/details/en/c/266219/ (accessed on 15 December 2022).
2. Ashokkumar, V.; Flora, G.; Venkatkarthick, R.; SenthilKannan, K.; Kuppam, C.; Mary Stephy, G.; Kamyab, H.; Chen, W.H.; Thomas, J.; Ngamcharussrivichai, C. Advanced Technologies on the Sustainable Approaches for Conversion of Organic Waste to Valuable Bioproducts: Emerging Circular Bioeconomy Perspective. *Fuel* **2022**, *324*, 124313. [CrossRef]
3. Gonçalves, M.L.M.B.B.; Maximo, G.J. Circular Economy in the Food Chain: Production, Processing and Waste Management. *Circ. Econ. Sustain.* **2022**. [CrossRef] [PubMed]
4. Visco, A.; Scolaro, C.; Facchin, M.; Brahimi, S.; Belhamdi, H.; Gatto, V.; Beghetto, V. Agri-Food Wastes for Bioplastics: European Prospective on Possible Applications in Their Second Life for a Circular Economy. *Polymers* **2022**, *14*, 2752. [CrossRef] [PubMed]
5. Zhu, Z.; Liu, W.; Ye, S.; Batista, L. Packaging Design for the Circular Economy: A Systematic Review. *Sustain. Prod. Consum.* **2022**, *32*, 817–832. [CrossRef]
6. European Commission. *An EU Action Plan for the Circular Economy*; European Commission: Brussels, Belgium, 2015.
7. European Commission. *A Sustainable Bioeconomy for Europe: Strengthening the Connection between Economy, Society and the Environment*; European Commission: Brussels, Belgium, 2018.
8. Petit-Boix, A.; Leipold, S. Circular Economy in Cities: Reviewing How Environmental Research Aligns with Local Practices. *J. Clean. Prod.* **2018**, *195*, 1270–1281. [CrossRef]
9. Zhu, B.; Nguyen, M.; Sarm Siri, N.; Malik, A. Towards a Transformative Model of Circular Economy for SMEs. *J. Bus. Res.* **2022**, *144*, 545–555. [CrossRef]
10. Girard, G. Does Circular Bioeconomy Contain Singular Social Science Research Questions, Especially Regarding Agriculture–Industry Nexus? *Clean. Circ. Bioeconomy* **2022**, *3*, 100030. [CrossRef]
11. Mouzakitis, Y.; Adamides, E.D. Techno-Economic Assessment of an Olive Mill Wastewater (OMWW) Biorefinery in the Context of Circular Bioeconomy. *Eng* **2022**, *3*, 488–503. [CrossRef]
12. Salvador, R.; Puglieri, F.N.; Halog, A.; de Andrade, F.G.; Piekarski, C.M.; De Francisco, A.C. Key Aspects for Designing Business Models for a Circular Bioeconomy. *J. Clean. Prod.* **2021**, *278*, 124341. [CrossRef]
13. Venkata Mohan, S.; Dahiya, S.; Amulya, K.; Katakojwala, R.; Vanitha, T.K. Can Circular Bioeconomy Be Fueled by Waste Biorefineries—A Closer Look. *Bioresour. Technol. Rep.* **2019**, *7*, 100277. [CrossRef]
14. Carus, M.; Dammer, L. The Circular Bioeconomy–Concepts, Opportunities, and Limitations. *Ind. Biotechnol.* **2018**, *14*, 83–91. [CrossRef]
15. Giampietro, M. On the Circular Bioeconomy and Decoupling: Implications for Sustainable Growth. *Ecol. Econ.* **2019**, *162*, 143–156. [CrossRef]
16. Ortega, F.; Versino, F.; López, O.V.; García, M.A. Biobased Composites from Agro-Industrial Wastes and by-Products. *Emergent Mater.* **2021**, 1–49. [CrossRef]
17. Cristóbal, J.; Caldeira, C.; Corrado, S.; Sala, S. Techno-Economic and Profitability Analysis of Food Waste Biorefineries at European Level. *Bioresour. Technol.* **2018**, *259*, 244–252. [CrossRef]
18. Jorissen, T.; Oraby, A.; Recke, G.; Zibek, S. A Systematic Analysis of Economic Evaluation Studies of Second-Generation Biorefineries Providing Chemicals by Applying Biotechnological Processes. *Biofuels Bioprod. Biorefining* **2020**, *14*, 1028–1045. [CrossRef]
19. Banerjee, S.; Munagala, M.; Shastri, Y.; Vijayaraghavan, R.; Patti, A.F.; Arora, A. Process Design and Techno-Economic Feasibility Analysis of an Integrated Pineapple Processing Waste Biorefinery. *ACS Eng. Au* **2022**, *2*, 208–218. [CrossRef]
20. Zhang, H.; Sablani, S. Biodegradable Packaging Reinforced with Plant-Based Food Waste and by-Products. *Curr. Opin. Food Sci.* **2021**, *42*, 61–68. [CrossRef]
21. Baetge, S.; Martin, K. Rice Straw and Rice Husks as Energy Sources—Comparison of Direct Combustion and Biogas Production. *Biomass Convers. Biorefinery* **2018**, *8*, 719–737. [CrossRef]
22. Rezaei, M.; Liu, B. Food Loss and Waste in the Food Supply Chain. *Nutfruit* **2017**, *2017*, 26–27.
23. Szymańska-Chargot, M.; Chylińska, M.; Gdula, K.; Kozioł, A.; Zdunek, A. Isolation and Characterization of Cellulose from Different Fruit and Vegetable Pomaces. *Polymers* **2017**, *9*, 495. [CrossRef]
24. Guillard, V.; Gaucel, S.; Fornaciari, C.; Angellier-Coussy, H.; Buche, P.; Gontard, N. The Next Generation of Sustainable Food Packaging to Preserve Our Environment in a Circular Economy Context. *Front. Nutr.* **2018**, *5*, 1–13. [CrossRef]
25. Abotbina, W.; Sapuan, S.M.; Ilyas, R.A.; Sultan, M.T.H.; Alkbir, M.F.M.; Sulaiman, S.; Harussani, M.M.; Bayraktar, E. Recent Developments in Cassava (Manihot Esculenta) Based Biocomposites and Their Potential Industrial Applications: A Comprehensive Review. *Materials* **2022**, *15*, 6992. [CrossRef] [PubMed]
26. Singh, E.; Mishra, R.; Kumar, A.; Shukla, S.K.; Lo, S.L.; Kumar, S. Circular Economy-Based Environmental Management Using Biochar: Driving towards Sustainability. *Process Saf. Environ. Prot.* **2022**, *163*, 585–600. [CrossRef]
27. Gupta, H.; Kumar, H.; Kumar, M.; Gehlaut, A.K.; Gaur, A.; Sachan, S.; Park, J.-W. Synthesis of Biodegradable Films Obtained from Rice Husk and Sugarcane Bagasse to Be Used as Food Packaging Material. *Environ. Eng. Res.* **2020**, *25*, 506–514. [CrossRef]

28. Jonglertjunya, W.; Juntong, T.; Pakkang, N.; Srimarut, N.; Sakdaronnarong, C. Properties of Lignin Extracted from Sugarcane Bagasse and Its Efficacy in Maintaining Postharvest Quality of Limes during Storage. *LWT-Food Sci. Technol.* **2014**, *57*, 116–125. [CrossRef]
29. Azmin, S.N.H.M.; Hayat, N.A.; Binti, M.; Nor, M.S.M. Development and Characterization of Food Packaging Bioplastic Film from Cocoa Pod Husk Cellulose Incorporated with Sugarcane Bagasse Fibre. *J. Bioresour. Bioprod.* **2020**, *5*, 248–255. [CrossRef]
30. Berthet, M.-A.; Angellier-Coussy, H.; Chea, V.; Guillard, V.; Gastaldi, E.; Gontard, N. Sustainable Food Packaging: Valorising Wheat Straw Fibres for Tuning PHBV-Based Composites Properties. *Compos. Part A Appl. Sci. Manuf.* **2015**, *72*, 139–147. [CrossRef]
31. Castrillón, H.D.C.; Aguilar, C.M.G.; Álvarez, B.E.A. Circular Economy Strategies: Use of Corn Waste to Develop Biomaterials. *Sustainability* **2021**, *13*, 8356. [CrossRef]
32. Bishop, G.; Styles, D.; Lens, P.N.L. Environmental Performance of Bioplastic Packaging on Fresh Food Produce: A Consequential Life Cycle Assessment. *J. Clean. Prod.* **2021**, *317*, 128377. [CrossRef]
33. Manrich, A.; Moreira, F.K.V.; Otoni, C.G.; Lorevice, M.V.; Martins, M.A.; Mattoso, L.H.C. Hydrophobic Edible Films Made up of Tomato Cutin and Pectin. *Carbohydr. Polym.* **2017**, *164*, 83–91. [CrossRef]
34. Gorrasi, G.; Brachi, P.; Bugatti, V.; Viscusi, G. Valorization of Tomato Processing Residues Through the Production of Active Bio-Composites for Packaging Applications. *Front. Mater.* **2019**, 10. [CrossRef]
35. Follonier, S.; Goyder, M.S.; Silvestri, A.C.; Crelier, S.; Kalman, F.; Riesen, R.; Zinn, M. Fruit Pomace and Waste Frying Oil as Sustainable Resources for the Bioproduction of Medium-Chain-Length Polyhydroxyalkanoates. *Int. J. Biol. Macromol.* **2014**, *71*, 42–52. [CrossRef]
36. Oliveira, T.Í.S.; Zea-Redondo, L.; Moates, G.K.; Wellner, N.; Cross, K.; Waldron, K.W.; Azeredo, H.M.C. Pomegranate Peel Pectin Films as Affected by Montmorillonite. *Food Chem.* **2016**, *198*, 107–112. [CrossRef]
37. Ginting, M.H.S.; Hasibuan, R.; Lubis, M.; Alanjani, F.; Winoto, F.A.; Siregar, R.C. Utilization of Avocado Seeds as Bioplastic Films Filler Chitosan and Ethylene Glycol Plasticizer. *Asian J. Chem.* **2018**, *30*, 1569–1573. [CrossRef]
38. Tongnuanchan, P.; Benjakul, S.; Prodpran, T.; Pisuchpen, S.; Osako, K. Mechanical, Thermal and Heat Sealing Properties of Fish Skin Gelatin Film Containing Palm Oil and Basil Essential Oil with Different Surfactants. *Food Hydrocoll.* **2016**, *56*, 93–107. [CrossRef]
39. Obruca, S.; Benesova, P.; Kucera, D.; Petrik, S.; Marova, I. Biotechnological Conversion of Spent Coffee Grounds into Polyhydroxyalkanoates and Carotenoids. *New Biotechnol.* **2015**, *32*, 569–574. [CrossRef]
40. Galanakis, C.M.; Tornberg, E.; Gekas, V. A Study of the Recovery of the Dietary Fibres from Olive Mill Wastewater and the Gelling Ability of the Soluble Fibre Fraction. *LWT -Food Sci. Technol.* **2010**, *43*, 1009–1017. [CrossRef]
41. Khalifa, I.; Barakat, H.; El-Mansy, H.A.; Soliman, S.A. Preserving Apple (Malus Domestica Var. Anna) Fruit Bioactive Substances Using Olive Wastes Extract-Chitosan Film Coating. *Inf. Process. Agric.* **2017**, *4*, 90–99. [CrossRef]
42. Licciardello, F.; Wittenauer, J.; Saengerlaub, S.; Reinelt, M.; Stramm, C. Rapid Assessment of the Effectiveness of Antioxidant Active Packaging-Study with Grape Pomace and Olive Leaf Extracts. *Food Packag. Shelf Life* **2015**, *6*, 1–6. [CrossRef]
43. Kaisangsri, N.; Kerdchoechuen, O.; Laohakunjit, N. Biodegradable Foam Tray from Cassava Starch Blended with Natural Fiber and Chitosan. *Ind. Crops Prod.* **2012**, *37*, 542–546. [CrossRef]
44. Torres-León, C.; Vicente, A.A.; Flores-López, M.L.; Rojas, R.; Serna-Cock, L.; Alvarez-Pérez, O.B.; Aguilar, C.N. Edible Films and Coatings Based on Mango (Var. Ataulfo) by-Products to Improve Gas Transfer Rate of Peach. *LWT* **2018**, *97*, 624–631. [CrossRef]
45. Chollakup, R.; Kongtud, W.; Sukatta, U.; Premchookiat, M.; Piriyasatits, K.; Nimitkeatkai, H.; Jarerat, A. Eco-Friendly Rice Straw Paper Coated with Longan (Dimocarpus Longan) Peel Extract as Bio-Based and Antibacterial Packaging. *Polymers* **2021**, *13*, 3096. [CrossRef] [PubMed]
46. Cruz, M.V.; Paiva, A.; Lisboa, P.; Freitas, F.; Alves, V.D.; Simões, P.; Barreiros, S.; Reis, M.A.M. Production of Polyhydroxyalkanoates from Spent Coffee Grounds Oil Obtained by Supercritical Fluid Extraction Technology. *Bioresour. Technol.* **2014**, *157*, 360–363. [CrossRef] [PubMed]
47. Boccalon, E.; Gorrasi, G. Functional Bioplastics from Food Residual: Potentiality and Safety Issues. *Compr. Rev. Food Sci. Food Saf.* **2022**, *21*, 3177–3204. [CrossRef]
48. George, N.; Debroy, A.; Bhat, S.; Singh, S.; Bindal, S. Biowaste to Bioplastics: An Ecofriendly Approach for A Sustainable Future. *J Appl. Biotechnol. Rep.* **2021**, *8*, 221–233. [CrossRef]
49. Sorrentino, A.; Gorrasi, G.; Vittoria, V. Permeability in Clay/Polyesters Nano-Biocomposites. In *Environmental Silicate Nano-Biocomposites*; Avérous, L., Pollet, E., Eds.; Green Energy and Technology; Springer: London, UK, 2012; pp. 237–264. ISBN 978-1-4471-4108-2.
50. Hernández-Muñoz, P.; Kanavouras, A.; Ng, P.; Gavara, R. Development and Characterization of Biodegradable Films Made from Wheat Gluten Protein Fractions. *J. Agric. Food Chem.* **2004**, *51*, 7647–7654. [CrossRef]
51. Álvarez-Castillo, E.; Bengoechea, C.; Felix, M.; Guerrero, A. Protein-Based Bioplastics from Biowastes: Sources, Processing, Properties and Applications. In *Bioplastics for Sustainable Development*; Kuddus, M., Roohi, Eds.; Springer: Singapore, 2021; pp. 137–176. ISBN 9789811618239.
52. Park, H.-Y.; Kim, S.-J.; Kim, K.M.; You, Y.-S.; Kim, S.Y.; Han, J. Development of Antioxidant Packaging Material by Applying Corn-Zein to LLDPE Film in Combination with Phenolic Compounds. *J. Food Sci.* **2012**, *77*, E273–E279. [CrossRef]

53. Gaona-Sánchez, V.A.; Calderón-Domínguez, G.; Morales-Sánchez, E.; Chanona-Pérez, J.J.; Velázquez-de la Cruz, G.; Méndez-Méndez, J.V.; Terrés-Rojas, E.; Farrera-Rebollo, R.R. Preparation and Characterisation of Zein Films Obtained by Electrospraying. *Food Hydrocoll.* **2015**, *49*, 1–10. [CrossRef]
54. Wittaya, T. Protein-Based Edible Films: Characteristics and Improvement of Properties. In *Structure and Function of Food Engineering*; Amer Eissa, A., Ed.; IntechOpen: London, UK, 2012; ISBN 978-953-51-0695-1.
55. Jerez, A.; Partal, P.; Martínez, I.; Gallegos, C.; Guerrero, A. Protein-Based Bioplastics: Effect of Thermo-Mechanical Processing. *Rheol. Acta* **2007**, *46*, 711–720. [CrossRef]
56. Dilshad, E.; Waheed, H.; Ali, U.; Amin, A.; Ahmed, I. General Structure and Classification of Bioplastics and Biodegradable Plastics. In *Bioplastics for Sustainable Development*; Kuddus, M., Roohi, Eds.; Springer: Singapore, 2021; pp. 61–82. ISBN 9789811618239.
57. Jiménez-Rosado, M.; Zarate-Ramírez, L.S.; Romero, A.; Bengoechea, C.; Partal, P.; Guerrero, A. Bioplastics Based on Wheat Gluten Processed by Extrusion. *J. Clean. Prod.* **2019**, *239*, 117994. [CrossRef]
58. Patni, N.; Yadava, P.; Agarwal, A.; Maroo, V. An Overview on the Role of Wheat Gluten as a Viable Substitute for Biodegradable Plastics. *Rev. Chem. Eng.* **2014**, *30*. [CrossRef]
59. Onyeaka, H.; Obileke, K.; Makaka, G.; Nwokolo, N. Current Research and Applications of Starch-Based Biodegradable Films for Food Packaging. *Polymers* **2022**, *14*, 1126. [CrossRef]
60. Abral, H.; Hartono, J. Moisture Absorption of Starch Based Biocomposites Reinforced with Water Hyacinth Fibers. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *213*, 12035. [CrossRef]
61. Jiang, T.; Duan, Q.; Zhu, J.; Liu, H.; Yu, L. Starch-Based Biodegradable Materials: Challenges and Opportunities. *Adv. Ind. Eng. Polym. Res.* **2020**, *3*, 8–18. [CrossRef]
62. Nasir, N.; Othman, S. The Physical and Mechanical Properties of Corn-Based Bioplastic Films with Different Starch and Glycerol Content. *J. Phys. Sci.* **2021**, *32*, 89–101. [CrossRef]
63. Diyana, Z.N.; Jumaidin, R.; Selamat, M.Z.; Ghazali, I.; Julmohammad, N.; Huda, N.; Ilyas, R.A. Physical Properties of Thermoplastic Starch Derived from Natural Resources and Its Blends: A Review. *Polymers* **2021**, *13*, 1396. [CrossRef]
64. Amaraweera, S.M.; Gunathilake, C.; Gunawardene, O.H.P.; Fernando, N.M.L.; Wanninayaka, D.B.; Dassanayake, R.S.; Rajapaksha, S.M.; Manamperi, A.; Fernando, C.A.N.; Kulatunga, A.K.; et al. Development of Starch-Based Materials Using Current Modification Techniques and Their Applications: A Review. *Molecules* **2021**, *26*, 6880. [CrossRef]
65. Li, M.-C.; Lee, J.K.; Cho, U.R. Synthesis, Characterization, and Enzymatic Degradation of Starch-Grafted Poly(Methyl Methacrylate) Copolymer Films. *J. Appl. Polym. Sci.* **2012**, *125*, 405–414. [CrossRef]
66. Fadeyibi, A.; Osunde, Z.D.; Egwim, E.C.; Idah, P.A. Performance Evaluation of Cassava Starch-Zinc Nanocomposite Film for Tomatoes Packaging. *J. Agric. Eng.* **2017**, *48*. [CrossRef]
67. Fitch-Vargas, P.R.; Camacho-Hernández, I.L.; Martínez-Bustos, F.; Islas-Rubio, A.R.; Carrillo-Cañedo, K.I.; Calderón-Castro, A.; Jacobo-Valenzuela, N.; Carrillo-López, A.; Delgado-Nieblas, C.I.; Aguilar-Palazuelos, E. Mechanical, Physical and Microstructural Properties of Acetylated Starch-Based Biocomposites Reinforced with Acetylated Sugarcane Fiber. *Carbohydr. Polym.* **2019**, *219*, 378–386. [CrossRef]
68. Travalini, A.P.; Lamsal, B.; Magalhães, W.L.E.; Demiate, I.M. Cassava Starch Films Reinforced with Lignocellulose Nanofibers from Cassava Bagasse. *Int. J. Biol. Macromol.* **2019**, *139*, 1151–1161. [CrossRef] [PubMed]
69. Karlovits, I. Lignocellulosic Bio-Refinery Downstream Products in Future Packaging Applications. *Int. Symp. Graph. Eng. Des.* **2020**, 39–53. [CrossRef]
70. Tajeddin, B. Cellulose-Based Polymers for Packaging Applications. In *Lignocellulosic Polymer Composites: Processing, Characterization, and Properties*; Scrivener Publishing LLC: Beverly, MA, USA, 2014; pp. 477–498. ISBN 978-1-118-77357-4.
71. Shaghaleh, H.; Xu, X.; Wang, S. Current Progress in Production of Biopolymeric Materials Based on Cellulose, Cellulose Nanofibers, and Cellulose Derivatives. *RSC Adv.* **2018**, *8*, 825–842. [CrossRef] [PubMed]
72. Nanda, S.; Patra, B.R.; Patel, R.; Bakos, J.; Dalai, A.K. Innovations in Applications and Prospects of Bioplastics and Biopolymers: A Review. *Environ. Chem. Lett.* **2022**, *20*, 379–395. [CrossRef] [PubMed]
73. Liyanage, S.; Acharya, S.; Parajuli, P.; Shamshina, J.L.; Abidi, N. Production and Surface Modification of Cellulose Bioproducts. *Polymers* **2021**, *13*, 3433. [CrossRef]
74. Yaradoddi, J.S.; Banapurmath, N.R.; Ganachari, S.V.; Soudagar, M.E.M.; Mubarak, N.M.; Hallad, S.; Hugar, S.; Fayaz, H. Biodegradable Carboxymethyl Cellulose Based Material for Sustainable Packaging Application. *Sci. Rep.* **2020**, *10*, 21960. [CrossRef]
75. Zhang, X.; Guo, H.; Luo, W.; Chen, G.; Xiao, N.; Xiao, G.; Liu, C. Development of Functional Hydroxyethyl Cellulose-Based Composite Films for Food Packaging Applications. *Front. Bioeng. Biotechnol.* **2022**, *10*, 989893. [CrossRef]
76. Li, J.; Zhang, F.; Zhong, Y.; Zhao, Y.; Gao, P.; Tian, F.; Zhang, X.; Zhou, R.; Cullen, P.J. Emerging Food Packaging Applications of Cellulose Nanocomposites: A Review. *Polymers* **2022**, *14*, 4025. [CrossRef]
77. Perumal, A.B.; Nambiar, R.B.; Moses, J.A.; Anandharamakrishnan, C. Nanocellulose: Recent Trends and Applications in the Food Industry. *Food Hydrocoll.* **2022**, *127*, 107484. [CrossRef]
78. Silva, F.A.G.S.; Dourado, F.; Gama, M.; Poças, F. Nanocellulose Bio-Based Composites for Food Packaging. *Nanomaterials* **2020**, *10*, 2041. [CrossRef]
79. Sun, X.; Wu, Q.; Zhang, X.; Ren, S.; Lei, T.; Li, W.; Xu, G.; Zhang, Q. Nanocellulose Films with Combined Cellulose Nanofibers and Nanocrystals: Tailored Thermal, Optical and Mechanical Properties. *Cellulose* **2018**, *25*, 1103–1115. [CrossRef]

80. Shi, H.; Wu, L.; Luo, Y.; Yu, F.; Li, H. A Facile Method to Prepare Cellulose Fiber-Based Food Packaging Papers with Improved Mechanical Strength, Enhanced Barrier, and Antibacterial Properties. *Food Biosci.* **2022**, *48*, 101729. [CrossRef]
81. Brodnjak, U.V. Microorganism Based Biopolymer Materials for Packaging Applications: A Review. *J. Compos. Biodegrad. Polym.* **2016**, *4*, 32–40. [CrossRef]
82. Verdini, F.; Tabasso, S.; Mariatti, F.; Bosco, F.; Mollea, C.; Calcio Gaudino, E.; Cirio, A.; Cravotto, G. From Agri-Food Wastes to Polyhydroxyalkanoates through a Sustainable Process. *Fermentation* **2022**, *8*, 556. [CrossRef]
83. Szacherska, K.; Moraczewski, K.; Czaplicki, S.; Oleskowicz-Popiel, P.; Mozejko-Ciesielska, J. Effect of Short- and Medium-Chain Fatty Acid Mixture on Polyhydroxyalkanoate Production by Pseudomonas Strains Grown under Different Culture Conditions. *Front. Bioeng. Biotechnol.* **2022**, *10*, 1583. [CrossRef]
84. Bulantekin, Ö.; Alp, D.; Bulantekin, Ö.; Alp, D. *Development of Food Packaging Films from Microorganism-Generated Polyhydroxyalkanoates*; IntechOpen: London, UK, 2022; ISBN 978-1-80356-996-3.
85. Koller, M. Poly(Hydroxyalkanoates) for Food Packaging: Application and Attempts towards Implementation. *Appl. Food Technol. Biotechnol.* **2014**, *1*, 3–15. [CrossRef]
86. Reddy, V.U.N.; Ramanaiah, S.V.; Reddy, M.V.; Chang, Y.-C. Review of the Developments of Bacterial Medium-Chain-Length Polyhydroxyalkanoates (Mcl-PHAs). *Bioengineering* **2022**, *9*, 225. [CrossRef]
87. Awasthi, M.K.; Kumar, V.; Yadav, V.; Sarsaiya, S.; Awasthi, S.K.; Sindhu, R.; Binod, P.; Kumar, V.; Pandey, A.; Zhang, Z. Current State of the Art Biotechnological Strategies for Conversion of Watermelon Wastes Residues to Biopolymers Production: A Review. *Chemosphere* **2022**, *290*, 133310. [CrossRef]
88. Pereira, J.R.; Araújo, D.; Freitas, P.; Marques, A.C.; Alves, V.D.; Sevrin, C.; Grandfils, C.; Fortunato, E.; Reis, M.A.M.; Freitas, F. Production of Medium-Chain-Length Polyhydroxyalkanoates by Pseudomonas Chlororaphis Subsp. Aurantiaca: Cultivation on Fruit Pulp Waste and Polymer Characterization. *Int. J. Biol. Macromol.* **2021**, *167*, 85–92. [CrossRef]
89. Angelini, S.; Cerruti, P.; Immirzi, B.; Scarinzi, G.; Malinconico, M. Acid-Insoluble Lignin and Holocellulose from a Lignocellulosic Biowaste: Bio-Fillers in Poly(3-Hydroxybutyrate). *Eur. Polym. J.* **2016**, *76*, 63–76. [CrossRef]
90. Nosal, H.; Moser, K.; Warzała, M.; Holzer, A.; Stańczyk, D.; Sabura, E. Selected Fatty Acids Esters as Potential PHB-V Bioplasticizers: Effect on Mechanical Properties of the Polymer. *J. Polym. Environ.* **2021**, *29*, 38–53. [CrossRef]
91. de Sousa Junior, R.R.; dos Santos, C.A.S.; Ito, N.M.; Suqueira, A.N.; Lackner, M.; dos Santos, D.J. PHB Processability and Property Improvement with Linear-Chain Polyester Oligomers Used as Plasticizers. *Polymers* **2022**, *14*, 4197. [CrossRef] [PubMed]
92. Vu, D.H.; Wainaina, S.; Taherzadeh, M.J.; Åkesson, D.; Ferreira, J.A. Production of Polyhydroxyalkanoates (PHAs) by Bacillus Megaterium Using Food Waste Acidogenic Fermentation-Derived Volatile Fatty Acids. *Bioengineered* **2021**, *12*, 2480–2498. [CrossRef] [PubMed]
93. Castro-Aguirre, E.; Iñiguez-Franco, F.; Samsudin, H.; Fang, X.; Auras, R. Poly(Lactic Acid)—Mass Production, Processing, Industrial Applications, and End of Life. *Adv. Drug Deliv. Rev.* **2016**, *107*, 333–366. [CrossRef]
94. Muneer, F.; Nadeem, H.; Arif, A.; Zaheer, W. Bioplastics from Biopolymers: An Eco-Friendly and Sustainable Solution of Plastic Pollution. *Polym. Sci. Ser. C* **2021**, *63*, 47–63. [CrossRef]
95. Nduko, J.M.; Taguchi, S. Microbial Production of Biodegradable Lactate-Based Polymers and Oligomeric Building Blocks From Renewable and Waste Resources. *Front. Bioeng. Biotechnol.* **2021**, *8*, 77. [CrossRef]
96. Boey, J.Y.; Mohamad, L.; Khok, Y.S.; Tay, G.S.; Baidurah, S. A Review of the Applications and Biodegradation of Polyhydroxyalkanoates and Poly(Lactic Acid) and Its Composites. *Polymers* **2021**, *13*, 1544. [CrossRef]
97. Jem, K.J.; Tan, B. The Development and Challenges of Poly (Lactic Acid) and Poly (Glycolic Acid). *Adv. Ind. Eng. Polym. Res.* **2020**, *3*, 60–70. [CrossRef]
98. Suaduang, N.; Ross, S.; Ross, G.M.; Wangsoub, S.; Mahasaranon, S. The Physical and Mechanical Properties of Biocomposite Films Composed of Poly(Lactic Acid) with Spent Coffee Grounds. *Key Eng. Mater.* **2019**, *824*, 87–93. [CrossRef]
99. Ma, Y.; Li, L.; Wang, Y. Development of PLA-PHB-Based Biodegradable Active Packaging and Its Application to Salmon. *Packag. Technol. Sci.* **2018**, *31*, 739–746. [CrossRef]
100. Li, T.; Chen, C.; Brozena, A.H.; Zhu, J.Y.; Xu, L.; Driemeier, C.; Dai, J.; Rojas, O.J.; Isogai, A.; Wågberg, L.; et al. Developing Fibrillated Cellulose as a Sustainable Technological Material. *Nature* **2021**, *590*, 47–56. [CrossRef]
101. Huang, S.; Xue, Y.; Yu, B.; Wang, L.; Zhou, C.; Ma, Y. A Review of the Recent Developments in the Bioproduction of Polylactic Acid and Its Precursors Optically Pure Lactic Acids. *Molecules* **2021**, *26*, 6446. [CrossRef]
102. Duan, B.; Huang, Y.; Lu, A.; Zhang, L. Recent Advances in Chitin Based Materials Constructed via Physical Methods. *Prog. Polym. Sci.* **2018**, *82*, 1–33. [CrossRef]
103. Azofeifa, D.E.; Arguedas, H.J.; Vargas, W.E. Optical Properties of Chitin and Chitosan Biopolymers with Application to Structural Color Analysis. *Opt. Mater.* **2012**, *35*, 175–183. [CrossRef]
104. Priyadarshi, R.; Rhim, J.-W. Chitosan-Based Biodegradable Functional Films for Food Packaging Applications. *Innov. Food Sci. Emerg. Technol.* **2020**, *62*, 102346. [CrossRef]
105. Khaled, A. A Review on Natural Biodegradable Materials: Chitin and Chitosan. *Chem. Adv. Mater.* **2021**, *6*, 1–5.
106. Pandharipande, S.; Bhagat, P.; Tech, B.; Semester, T. Synthesis of Chitin from Crab Shells and Its Utilization in Preparation of Nanostructured Film. *Int. J. Sci. Eng. Technol. Res.* **2016**, *5*, 2278–7798.
107. Costa, S.M.; Ferreira, D.P.; Teixeira, P.; Ballesteros, L.F.; Teixeira, J.A.; Fangueiro, R. Active Natural-Based Films for Food Packaging Applications: The Combined Effect of Chitosan and Nanocellulose. *Int. J. Biol. Macromol.* **2021**, *177*, 241–251. [CrossRef]

108. Rubilar, J. Effect of Antioxidant and Optimal Antimicrobial Mixtures of Carvacrol, Grape Seed Extract and Chitosan on Different Spoilage Microorganisms and Their Application as Coatings on Different Food Matrices. *Int. J. Food Stud.* **2013**, *2*, 22–38. [CrossRef]
109. Wan, A.; Xu, Q.; Li, H. Antioxidant Activity of High Molecular Weight Chitosan and N,O-Quaternized Chitosans. *J. Agric. Food Chem.* **2013**, *61*. [CrossRef]
110. Bonilla, J.; Sobral, P.J.A. Gelatin-Chitosan Edible Film Activated with Boldo Extract for Improving Microbiological and Antioxidant Stability of Sliced Prato Cheese. *Int. J. Food Sci. Technol.* **2019**, *54*, 1617–1624. [CrossRef]
111. Kasai, D.R.; Radhika, D.; Chalannavar, R.K.; Chougale, R.B.; Mudigoudar, B.; Kasai, D.R.; Radhika, D.; Chalannavar, R.K.; Chougale, R.B.; Mudigoudar, B. *A Study on Edible Polymer Films for Food Packaging Industry: Current Scenario and Advancements*; IntechOpen: London, UK, 2022; ISBN 978-1-83768-226-3.
112. Rhim, J.W.; Shellhammer, T.H. Lipid-Based Edible Films and Coatings. In *Innovations in Food Packaging*; Han, J.H., Ed.; Food Science and Technology; Elsevier: London, UK, 2005; pp. 362–383. ISBN 978-0-12-311632-1.
113. Baghi, F.; Gharsallaoui, A.; Dumas, E.; Ghnimi, S. Advancements in Biodegradable Active Films for Food Packaging: Effects of Nano/Microcapsule Incorporation. *Foods* **2022**, *11*, 760. [CrossRef] [PubMed]
114. Bouaziz, K.; Ayadi, M.; Allouche, N.; Chemtob, A. Renewable Photopolymer Films Derived from Low-Grade Lampante and Pomace Olive Oils. *Eur. J. Lipid Sci. Technol.* **2017**, *119*, 1700003. [CrossRef]
115. Chiumarelli, M.; Hubinger, M.D. Evaluation of Edible Films and Coatings Formulated with Cassava Starch, Glycerol, Carnauba Wax and Stearic Acid. *Food Hydrocoll.* **2014**, *38*, 20–27. [CrossRef]
116. Rodrigues, D.C.; Caceres, C.A.; Ribeiro, H.L.; de Abreu, R.F.A.; Cunha, A.P.; Azeredo, H.M.C. Influence of Cassava Starch and Carnauba Wax on Physical Properties of Cashew Tree Gum-Based Films. *Food Hydrocoll.* **2014**, *38*, 147–151. [CrossRef]
117. Mali, S. Biodegradable Foams in the Development of Food Packaging. In *Polymers for Food Applications*; Gutiérrez, T.J., Ed.; Springer International Publishing: Cham, Switzerland, 2018; pp. 329–345. ISBN 978-3-319-94624-5/978-3-319-94625-2.
118. Araque, L.M.; Alvarez, V.A.; Gutiérrez, T.J. Composite Foams Made from Biodegradable Polymers for Food Packaging Applications. In *Polymers for Food Applications*; Gutiérrez, T.J., Ed.; Springer International Publishing: Cham, Switzerland, 2018; pp. 347–355. ISBN 978-3-319-94624-5/978-3-319-94625-2.
119. Engel, J.B.; Ambrosi, A.; Tessaro, I.C. Development of Biodegradable Starch-Based Foams Incorporated with Grape Stalks for Food Packaging. *Carbohydr. Polym.* **2019**, *225*, 115234. [CrossRef]
120. Sohn, J.; Kim, H.; Cha, S. Bio-Based Foamed Cushioning Materials Using Polypropylene and Wheat Bran. *Sustainability* **2019**, *11*, 1670. [CrossRef]
121. de Carvalho, F.A.; Bilck, A.P.; Yamashita, F.; Mali, S. Baked Foams Based on Cassava Starch Coated with Polyvinyl Alcohol with a Higher Degree of Hydrolysis. *J. Polym. Environ.* **2018**, *26*, 1445–1452. [CrossRef]
122. Rodrigues, N.H.P.; de Souza, J.T.; Rodrigues, R.L.; Canteri, M.H.G.; Tramontin, S.M.K.; de Francisco, A.C. Starch-Based Foam Packaging Developed from a By-Product of Potato Industrialization (*Solanum tuberosum* L.). *Appl. Sci.* **2020**, *10*, 2235. [CrossRef]
123. Donati, N.; Spada, J.C.; Tessaro, I.C. Recycling Rice Husk Ash as a Filler on Biodegradable Cassava Starch-Based Foams. *Polym. Bull.* **2022**, *10*, 1–8. [CrossRef]
124. Amaraweera, S.M.; Gunathilake, C.; Gunawardene, O.H.P.; Dassanayake, R.S.; Fernando, N.M.L.; Wanninayaka, D.B.; Rajapaksha, S.M.; Manamperi, A.; Gangoda, M.; Manchanda, A.; et al. Preparation and Characterization of Dual-Modified Cassava Starch-Based Biodegradable Foams for Sustainable Packaging Applications. *ACS Omega* **2022**, *7*, 19579–19590. [CrossRef]
125. Cruz-Tirado, J.P.; Barros Ferreira, R.S.; Lizárraga, E.; Tapia-Blácido, D.R.; Silva, N.C.C.; Angelats-Silva, L.; Siche, R. Bioactive Andean Sweet Potato Starch-Based Foam Incorporated with Oregano or Thyme Essential Oil. *Food Packag. Shelf Life* **2020**, *23*, 100457. [CrossRef]
126. Teixeira, S.C.; Soares, N.F.F.; Stringheta, P.C. Development of Colorimetric Altered Intelligent Packaging Incorporated with Anthocyanins: A Critical Review. *Braz. J. Food Technol.* **2021**, *24*, 2021033. [CrossRef]
127. Han, J.W.; Ruiz-Garcia, L.; Qian, J.P.; Yang, X.T. Food Packaging: A Comprehensive Review and Future Trends. *Compr. Rev. Food Sci. Food Saf.* **2018**, *17*, 860–877. [CrossRef]
128. Aman Mohammadi, M.; Dakhili, S.; Mirza Alizadeh, A.; Kooki, S.; Hassanzadazar, H.; Alizadeh-Sani, M.; McClements, D.J. New Perspectives on Electrospun Nanofiber Applications in Smart and Active Food Packaging Materials. *Crit. Rev. Food Sci. Nutr.* **2022**, *19*, 1–17. [CrossRef]
129. Siemann, U. Solvent Cast Technology—A Versatile Tool for Thin Film Production. In *Progress in Colloid & Polymer Science: Scattering Methods and the Properties of Polymer Materials*; Kremer, F., Richtering, W., Eds.; Springer: Berlin/Heidelberg, Germany, 2005; p. 175. ISBN 9783540253235.
130. Abdul Khalil, H.P.S.; Banerjee, A.; Saurabh, C.K.; Tye, Y.Y.; Suriani, A.B.; Mohamed, A.; Karim, A.A.; Rizal, S.; Paridah, M.T. Biodegradable Films for Fruits and Vegetables Packaging Application: Preparation and Properties. *Food Eng. Rev.* **2018**, *10*, 139–153. [CrossRef]
131. Rhim, J.W.; Mohanty, A.K.; Singh, S.P.; Ng, P.K.W. Effect of the Processing Methods on the Performance of Polylactide Films: Thermocompression versus Solvent Casting. *J. Appl. Polym. Sci.* **2006**, *101*, 3736–3742. [CrossRef]
132. Lin, Y.; Kang, K.; Chen, F.; Zhang, L.; Lavernia, E.J. Gradient Metal Matrix Composites. In *Comprehensive Composite Materials II*; Elsevier Ltd.: Amsterdam, The Netherlands, 2017; Volume 4, pp. 331–346. ISBN 9780081005330.

133. Scheibe, A.S.; De Moraes, J.O.; Laurindo, J.B. Production and Characterization of Bags from Biocomposite Films of Starch-Vegetal Fibers Prepared by Tape Casting. *J. Food Process Eng.* **2014**, *37*, 482–492. [CrossRef]
134. De Moraes, J.O.; Scheibe, A.S.; Sereno, A.; Laurindo, J.B. Scale-up of the Production of Cassava Starch Based Films Using Tape-Casting. *J. Food Eng.* **2013**, *119*, 800–808. [CrossRef]
135. Wang, H.; Qian, J.; Ding, F. Emerging Chitosan-Based Films for Food Packaging Applications. *J. Agric. Food Chem.* **2018**, *66*, 395–413. [CrossRef]
136. Rao, H.G.R.; Thejaswini, M.L. Extrusion Technology: A Novel Method Of Food Processing. *Int. J. Innov. Sci. Eng. Technol.* **2015**, *2*, 358–369.
137. Martínez-Camacho, A.P.; Cortez-Rocha, M.O.; Graciano-Verdugo, A.Z.; Rodríguez-Félix, F.; Castillo-Ortega, M.M.; Burgos-Hernández, A.; Ezquerra-Brauer, J.M.; Plascencia-Jatomea, M. Extruded Films of Blended Chitosan, Low Density Polyethylene and Ethylene Acrylic Acid. *Carbohydr. Polym.* **2013**, *91*, 666–674. [CrossRef] [PubMed]
138. Filli, K.B.; Jideani, A.I.O.; Jideani, V.A. Extrusion Bolsters Food Security in Africa. *Food Technol.* **2014**, *68*, 46–52.
139. García-Guzmán, L.; Cabrera-Barjas, G.; Soria-Hernández, C.G.; Castaño, J.; Guadarrama-Lezama, A.Y.; Llamazares, S.R. Progress in Starch-Based Materials for Food Packaging Applications. *Polysaccharides* **2022**, *14*, 136–177. [CrossRef]
140. Gómez-Estaca, J.; Gavara, R.; Catalá, R.; Hernández-Muñoz, P. The Potential of Proteins for Producing Food Packaging Materials: A Review. *Packag. Technol. Sci.* **2016**, *29*, 203–224. [CrossRef]
141. Packaging Europe Thermoforming With Biobased Plastics for Greater Sustainability. Available online: https://packagingeurope.com/thermoforming-with-biobased-plastics-for-greater-sustainability/1447.article (accessed on 15 December 2022).
142. Averous, L.; Fringant, C.; Moro, L. Starch-Based Biodegradable Materials Suitable for Thermoforming Packaging. *Starch* **2001**, *53*, 368. [CrossRef]
143. Tatara, R.A. Compression Molding. In *Applied Plastics Engineering Handbook: Processing, Materials, and Applications: Second Edition*; Elsevier Inc.: Amsterdam, The Netherlands, 2017; pp. 291–320. ISBN 9780323390408.
144. Soffarina, M. Methodology of Press System of Compression Moulding. 2016. Available online: https://www.researchgate.net/publication/301754897_Methodology_of_Press_System_of_Compression_Moulding?channel=doi&linkId=5725f2db08aee491cb3ef741&showFulltext=true (accessed on 12 March 2023). [CrossRef]
145. Zubeldía, F.; Ansorena, M.R.; Marcovich, N.E. Material Characterisation Wheat Gluten Films Obtained by Compression Molding. *Polym. Test.* **2015**, *43*, 68–77. [CrossRef]
146. Ceballos, R.L.; Ochoa-Yepes, O.; Goyanes, S.; Bernal, C.; Famá, L. Effect of Yerba Mate Extract on the Performance of Starch Films Obtained by Extrusion and Compression Molding as Active and Smart Packaging. *Carbohydr. Polym.* **2020**, *244*, 116495. [CrossRef]
147. Li, F.; Biagioni, P.; Finazzi, M.; Tavazzi, S.; Piergiovanni, L. Tunable Green Oxygen Barrier through Layer-by-Layer Self-Assembly of Chitosan and Cellulose Nanocrystals. *Carbohydr. Polym.* **2013**, *92*, 2128–2134. [CrossRef]
148. Richardson, J.J.; Cui, J.; Björnmalm, M.; Braunger, J.A.; Ejima, H.; Caruso, F. Innovation in Layer-by-Layer Assembly. *Chem. Rev.* **2016**, *116*, 14828–14867. [CrossRef]
149. Goksen, G.; Nisha, P.; Ibrahim Ekiz, H. Electrospinning Technology: Its Process Conditions and Food Packaging Applications. In *Food Engineering Series*; Režek Jambrak, A., Ed.; Springer: Cham, Switzerland, 2022; pp. 447–468.
150. Leidy, R.; Maria Ximena, Q.-C. Use of Electrospinning Technique to Produce Nanofibres for Food Industries: A Perspective from Regulations to Characterisations. *Trends Food Sci. Technol.* **2019**, *85*, 92–106. [CrossRef]
151. Dhiman, A.; Suhag, R.; Singh, A.; Prabhakar, P.K. Mechanistic Understanding and Potential Application of Electrospraying in Food Processing: A Review. *Crit. Rev. Food Sci. Nutr.* **2022**, *62*, 8288–8306. [CrossRef]
152. Zhao, L.; Duan, G.; Zhang, G.; Yang, H.; Jiang, S.; He, S. Electrospun Functional Materials toward Food Packaging Applications: A Review. *Nanomaterials* **2020**, *10*, 150. [CrossRef]
153. Zhu, L. Biorefinery as a Promising Approach to Promote Microalgae Industry: An Innovative Framework. *Renew. Sustain. Energy Rev.* **2015**, *41*, 1376–1384. [CrossRef]
154. Yaashikaa, P.; Senthil Kumar, P.; Varjani, S. Valorization of Agro-Industrial Wastes for Biorefinery Process and Circular Bioeconomy: A Critical Review. *Bioresour. Technol.* **2022**, *343*, 126126. [CrossRef]
155. Demirbas, A.; Fatih Demirbas, M. Importance of Algae Oil as a Source of Biodiesel. *Energy Convers. Manag.* **2011**, *52*, 163–170. [CrossRef]
156. Jõgi, K.; Bhat, R. Valorization of Food Processing Wastes and By-Products for Bioplastic Production. *Sustain. Chem. Pharm.* **2020**, *18*, 100326. [CrossRef]
157. Redondo-Gómez, C.; Quesada, M.R.; Astúa, S.V.; Zamora, J.P.M.; Lopretti, M.; Vega-Baudrit, J.R. Biorefinery of Biomass of Agro-Industrial Banana Waste to Obtain High-Value Biopolymers. *Molecules* **2020**, *25*, 3829. [CrossRef]
158. Panyasiri, P.; Yingkamhaeng, N.; Lam, N.T.; Sukyai, P. Extraction of Cellulose Nanofibrils from Amylase-Treated Cassava Bagasse Using High-Pressure Homogenization. *Cellulose* **2018**, *25*, 1757–1768. [CrossRef]
159. Saelee, K.; Yingkamhaeng, N.; Nimchua, T.; Sukyai, P. An Environmentally Friendly Xylanase-Assisted Pretreatment for Cellulose Nanofibrils Isolation from Sugarcane Bagasse by High-Pressure Homogenization. *Ind. Crops Prod.* **2016**, *82*, 149–160. [CrossRef]
160. Espinosa, E.; Rol, F.; Bras, J.; Rodríguez, A. Production of Lignocellulose Nanofibers from Wheat Straw by Different Fibrillation Methods. Comparison of Its Viability in Cardboard Recycling Process. *J. Clean. Prod.* **2019**, *239*, 118083. [CrossRef]

161. Hideno, A.; Abe, K.; Yano, H. Preparation Using Pectinase and Characterization of Nanofibers from Orange Peel Waste in Juice Factories. *J. Food Sci.* **2014**, *79*. [CrossRef] [PubMed]
162. Zhang, S.; Fan, X.; Lin, L.; Zhao, L.; Liu, A.; Wei, C. Properties of Starch from Root Tuber of Stephania Epigaea in Comparison with Potato and Maize Starches. *Int. J. Food Prop.* **2017**, *20*, 1740–1750. [CrossRef]
163. Repajić, M.; Cegledi, E.; Zorić, Z.; Pedisić, S.; Garofulić, I.E.; Radman, S.; Palčić, I.; Dragović-Uzelac, V. Bioactive Compounds in Wild Nettle (Urtica Dioica l.) Leaves and Stalks: Polyphenols and Pigments upon Seasonal and Habitat Variations. *Foods* **2021**, *10*, 190. [CrossRef]
164. Ngoc, H.N.; Mair, L.; Nghiem, D.T.; Le Thien, K.; Gostner, J.M.; Stuppner, H.; Ganzera, M. Phenolic Compounds from the Stems of Fissistigma Polyanthoides and Their Anti-Oxidant Activities. *Fitoterapia* **2019**, *137*, 104252. [CrossRef]
165. Lima, A.R.; Cristofoli, N.L.; Rosa, A.M. Comparative Study of the Production of Cellulose Nanofibers from Agro-Industrial Waste Streams of Salicornia Ramosissima by Acid and Enzymatic Treatment. *Food Bioprod. Process.* **2023**, *137*, 214–225. [CrossRef]
166. Nayak, A.; Bhushan, B. An Overview of the Recent Trends on the Waste Valorization Techniques for Food Wastes. *J. Environ. Manag.* **2019**, *233*, 352–370. [CrossRef]
167. Tsegaye, B.; Jaiswal, S.; Jaiswal, A.K. Food Waste Biorefinery: Pathway towards Circular Bioeconomy. *Foods* **2021**, *10*, 1174. [CrossRef]
168. Kumar, B.; Verma, P. Life Cycle Assessment: Blazing a Trail for Bioresources Management. *Energy Convers. Manag. X* **2020**, *10*, 100063. [CrossRef]
169. Naranjo, J.M.; Cardona, C.A.; Higuita, J.C. Use of Residual Banana for Polyhydroxybutyrate (PHB) Production: Case of Study in an Integrated Biorefinery. *Waste Manag.* **2014**, *34*, 2634–2640. [CrossRef]
170. Ioannidou, S.M.; Pateraki, C.; Ladakis, D.; Papapostolou, H.; Tsakona, M.; Vlysidis, A.; Kookos, I.K.; Koutinas, A. Sustainable Production of Bio-Based Chemicals and Polymers via Integrated Biomass Refining and Bioprocessing in a Circular Bioeconomy Context. *Bioresour. Technol.* **2020**, *307*, 123093. [CrossRef]
171. Ghisellini, P.; Cialani, C.; Ulgiati, S. A Review on Circular Economy: The Expected Transition to a Balanced Interplay of Environmental and Economic Systems. *J. Clean. Prod.* **2016**, *114*, 11–32. [CrossRef]
172. Thi, N.B.D.; Kumar, G.; Lin, C.Y. An Overview of Food Waste Management in Developing Countries: Current Status and Future Perspective. *J. Environ. Manag.* **2015**, *157*, 220–229. [CrossRef]
173. Simon, F. EU Official: Further Efforts Needed to Address 'Ecological Limits' of Biomass–EURACTIV.Com. Available online: https://www.euractiv.com/section/biomass/interview/eu-official-further-efforts-needed-to-address-ecological-limits-of-biomass/ (accessed on 23 March 2023).
174. European Commission. *Biorefineries Distribution in the EU*; Publications Office of the European Union: Brussels, Belgium, 2018.
175. Yadav, V.; Sarker, A.; Yadav, A.; Miftah, A.O.; Bilal, M.; Iqbal, H.M.N. Integrated Biorefinery Approach to Valorize Citrus Waste: A Sustainable Solution for Resource Recovery and Environmental Management. *Chemosphere* **2022**, *293*, 133459. [CrossRef]
176. Manhongo, T.T.; Chimphango, A.; Thornley, P.; Röder, M. Techno-Economic and Environmental Evaluation of Integrated Mango Waste Biorefineries. *J. Clean. Prod.* **2021**, *325*, 129335. [CrossRef]
177. Manhongo, T.T.; Chimphango, A.; Thornley, P.; Röder, M. An Economic Viability and Environmental Impact Assessment of Mango Processing Waste-Based Biorefineries for Co-Producing Bioenergy and Bioactive Compounds. *Renew. Sustain. Energy Rev.* **2021**, *148*, 111216. [CrossRef]
178. Demichelis, F.; Fiore, S.; Pleissner, D.; Venus, J. Technical and Economic Assessment of Food Waste Valorization through a Biorefinery Chain. *Renew. Sustain. Energy Rev.* **2018**, *94*, 38–48. [CrossRef]
179. Ortiz-Sanchez, M.; Solarte-Toro, J.C.; Orrego-Alzate, C.E.; Acosta-Medina, C.D.; Cardona-Alzate, C.A. Integral Use of Orange Peel Waste through the Biorefinery Concept: An Experimental, Technical, Energy, and Economic Assessment. *Biomass Convers. Biorefinery* **2021**, *11*, 645–659. [CrossRef]
180. Caldeira, C.; Vlysidis, A.; Fiore, G.; De Laurentiis, V.; Vignali, G.; Sala, S. Sustainability of Food Waste Biorefinery: A Review on Valorisation Pathways, Techno-Economic Constraints, and Environmental Assessment. *Bioresour. Technol.* **2020**, *312*, 123575. [CrossRef]
181. Giller, C.; Malkani, B.; Parasar, J. *Coffee to Biofuels*; Penn Libraries: Philadelphia, PA, USA, 2017.
182. Tokimoto, T.; Kawasaki, N.; Nakamura, T.; Akutagawa, J.; Tanada, S. Removal of Lead Ions in Drinking Water by Coffee Grounds as Vegetable Biomass. *J. Colloid Interface Sci.* **2005**, *281*, 56–61. [CrossRef]
183. Mussatto, S.I.; Machado, E.M.S.; Martins, S.; Teixeira, J.A. Production, Composition, and Application of Coffee and Its Industrial Residues. *Food Bioprocess Technol.* **2011**, *4*, 661–672. [CrossRef]
184. Kwon, E.E.; Yi, H.; Jeon, Y.J. Sequential Co-Production of Biodiesel and Bioethanol with Spent Coffee Grounds. *Bioresour. Technol.* **2013**, *136*, 475–480. [CrossRef] [PubMed]
185. Obruca, S.; Petrik, S.; Benesova, P.; Svoboda, Z.; Eremka, L.; Marova, I. Utilization of Oil Extracted from Spent Coffee Grounds for Sustainable Production of Polyhydroxyalkanoates. *Appl. Microbiol. Biotechnol.* **2014**, *98*, 5883–5890. [CrossRef] [PubMed]
186. IEA Bioenergy. *Bio-Based Chemicals: Value Added Products from Biorefineries*; IEA Bioenergy: Wageningen, The Netherlands, 2012.
187. Tock, J.Y.; Lai, C.L.; Lee, K.T.; Tan, K.T.; Bhatia, S. Banana Biomass as Potential Renewable Energy Resource: A Malaysian Case Study. *Renew. Sustain. Energy Rev.* **2010**, *14*, 798–805. [CrossRef]
188. Harish, K.; Srijana, M.; Madhusudhan, R.; Gopal, R. Coculture Fermentation of Banana Agro-Waste to Ethanol by Cellulolytic Thermophilic *Clostridium Thermocellum* CT2. *Afr. J. Biotechnol.* **2012**, *9*, 1926–1934. [CrossRef]

189. Duque, S.H.; Cardona, C.A.; Moncada, J. Techno-Economic and Environmental Analysis of Ethanol Production from 10 Agroindustrial Residues in Colombia. *Energy Fuels* **2015**, *29*, 775–783. [CrossRef]
190. Guerrero, A.B.; Ballesteros, I.; Ballesteros, M. The Potential of Agricultural Banana Waste for Bioethanol Production. *Fuel* **2018**, *213*, 176–185. [CrossRef]
191. Tarrés, Q.; Espinosa, E.; Domínguez-Robles, J.; Rodríguez, A.; Mutjé, P.; Delgado-Aguilar, M. The Suitability of Banana Leaf Residue as Raw Material for the Production of High Lignin Content Micro/Nano Fibers: From Residue to Value-Added Products. *Ind. Crops Prod.* **2017**, *99*, 27–33. [CrossRef]
192. Getachew, A.; Woldesenbet, F. Production of Biodegradable Plastic by Polyhydroxybutyrate (PHB) Accumulating Bacteria Using Low Cost Agricultural Waste Material. *BMC Res. Notes* **2016**, *9*, 1–9. [CrossRef]
193. Jiménez-Bonilla, P.; Salas-Arias, J.; Esquivel, M.; Vega-Baudrit, J.R. Optimization of Microwave-Assisted and Conventional Heating Comparative Synthesis of Poly(Lactic Acid) by Direct Melt Polycondensation from Agroindustrial Banana (Musa AAA Cavendish) and Pineapple (Ananas Comosus) Fermented Wastes. *J. Polym. Environ.* **2014**, *22*, 393–397. [CrossRef]
194. Vijay, R.; Tarika, K. Banana Peel as an Inexpensive Carbon Source for Microbial Polyhydroxyalkanoate (PHA) Production. *Int. Res. J. Environ. Aciences* **2018**, *7*, 28–36.
195. European Bioplastics Bioplastic Market Data. Available online: https://www.european-bioplastics.org/market/ (accessed on 4 January 2023).
196. Grand View Research. *Food Packaging Market Size, Share & Growth Report, 2030*; Grand View Research: San Francisco, CA, USA, 2022.
197. Grand View Research. *Global Industrial Starch Market Size Report, 2020–2028*; Grand View Research: San Francisco, CA, USA, 2021.
198. Facts & Factors. *Global Cellulose Fiber Market Size Worth*; Facts & Factors: Pune, India, 2022.
199. Fact.MR. *Pigments Market Size, Share Industry Growth 2031*; Fact.MR: Dublin, Ireland, 2021.
200. New Food. *Study Shows Growth in the Polysaccharides and Oligosaccharides Market*; New Food: Kent, UK, 2019.
201. Grand View Research. *Global Antimicrobial Coatings Market Size Report, 2030*; Grand View Research: San Francisco, CA, USA, 2021.
202. Grand View Research. *Chitosan Market Size-Global Industry Analysis Report, 2020–2027*; Grand View Research: San Francisco, CA, USA, 2021.
203. Fortune Business Insights. *Antioxidants Market Size, Share-Global Report [2021–2028]*; Fortune Business Insights: Pune, India, 2021.
204. Straits Research. *Pectin Market Trend, Growth to 2022–2030*; Straits Research: Pune, India, 2022.
205. Fortune Business Insights. *Polylactic Acid Market Size & Share-Global Report [2021–2028]*; Fortune Business Insights: Pune, India, 2021.
206. Fortune Business Insights. *Nanocellulose Market Size & Growth-Global Report [2020–2027]*; Fortune Business Insights: Pune, India, 2021.
207. Credence Research. *Polyhydroxybutyrate (PHB) Market Size, Trends & Share-2028*; Credence Research: Pune, India, 2021.
208. Global Market Insights. *Polyhydroxyalkanoate Market Size-Industry Report, 2022–2030*; Global Market Insights: Selbyville, DE, USA, 2022.
209. CelluForce About CelluForce. Available online: https://celluforce.com/about-celluforce/ (accessed on 24 January 2023).
210. VTT Cellulose Films and Coatings. Available online: https://www.vttresearch.com/en/ourservices/cellulose-films-and-coatings (accessed on 24 January 2023).
211. Tejayadi, S.; Cheryan, M. Lactic Acid from Cheese Whey Permeate. Productivity and Economics of a Continuous Membrane Bioreactor. *Appl. Microbiol. Biotechnol.* **1995**, *43*, 242–248. [CrossRef]
212. Pharmacompass Lactic Acid-Price Per Kg. Available online: https://www.pharmacompass.com/price/lactic-acid (accessed on 14 December 2022).
213. Biddy, M.J.; Scarlata, C.; Kinchin, C. *Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential*; Alliance for Sustainable Energy, LLC: Golden, CO, USA, 2016.
214. Alves de Oliveira, R.; Komesu, A.; Vaz Rossell, C.E.; Maciel Filho, R. Challenges and Opportunities in Lactic Acid Bioprocess Design—From Economic to Production Aspects. *Biochem. Eng. J.* **2018**, *133*, 219–239. [CrossRef]
215. Grand View Research. *Global Polylactic Acid Market Size Report, 2022–2030*; Grand View Research: San Francisco, CA, USA, 2022.
216. Galactic Galactic Group PLA Production Unit Was Launched in China. Available online: https://www.lactic.com/en/news/galactic-group-pla-production-unit-was-launched-china (accessed on 19 December 2022).
217. Futerro Futerro Aims to Set-up a New Fully Integrated PLA Biorefinery in Normandy, France. Available online: https://www.futerro.com/news-media/futerro-aims-set-new-fully-integrated-pla-biorefinery-normandy-france (accessed on 19 December 2022).
218. Corbion Alternative Feedstock-Sustainable Resource for Bioplastics. Available online: https://www.corbion.com/en/Innovation/Alternative-feedstock (accessed on 21 December 2022).
219. NatureWorks How Ingeo Is Made. Available online: https://www.natureworksllc.com/What-is-Ingeo/How-Ingeo-is-Made (accessed on 20 December 2022).
220. Lopez-Arenas, T.; González-Contreras, M.; Anaya-Reza, O.; Sales-Cruz, M. Analysis of the Fermentation Strategy and Its Impact on the Economics of the Production Process of PHB (Polyhydroxybutyrate). *Comput. Chem. Eng.* **2017**, *107*, 140–150. [CrossRef]
221. Bio-on Turn off Pollution. Available online: http://www.bio-on.it/?lin=portoghese (accessed on 21 December 2022).
222. Full Cycle Produce PHA Biopolymers. Available online: https://fullcyclebio.com/solutions/ (accessed on 4 January 2023).

223. Genecis Waste into High Value Materials. Available online: https://genecis.co/ (accessed on 3 January 2023).
224. European Bioplastics Market Drivers and Development. Available online: https://www.european-bioplastics.org/market/market-drivers/ (accessed on 5 January 2023).
225. Tsang, Y.F.; Kumar, V.; Samadar, P.; Yang, Y.; Lee, J.; Ok, Y.S.; Song, H.; Kim, K.-H.; Kwon, E.E.; Jeon, Y.J. Production of Bioplastic through Food Waste Valorization. *Environ. Int.* **2019**, *127*, 625–644. [CrossRef]
226. FoodPrint The Environmental Impact of Food Packaging. Available online: https://foodprint.org/issues/the-environmental-impact-of-food-packaging/#easy-footnote-bottom-1-1295 (accessed on 17 November 2022).
227. Shin, J.; Selke, S.E.M. Food Packaging. In *Food Processing: Principles and Applications*; Clark, S., Jung, S., Lamsal, B., Eds.; John Wiley & Sons, Ltd.: Hoboken, NJ, USA, 2014; pp. 249–268. ISBN 978-0-470-67114-6.
228. Ncube, L.K.; Ude, A.U.; Ogunmuyiwa, E.N.; Zulkifli, R.; Beas, I.N. Environmental Impact of Food Packaging Materials: A Review of Contemporary Development from Conventional Plastics to Polylactic Acid Based Materials. *Materials* **2020**, *13*, 4994. [CrossRef]
229. Licciardello, F. Packaging, Blessing in Disguise. Review on Its Diverse Contribution to Food Sustainability. *Trends Food Sci. Technol.* **2017**, *65*, 32–39. [CrossRef]
230. Peelman, N.; Ragaert, P.; De Meulenaer, B.; Adons, D.; Peeters, R.; Cardon, L.; Van Impe, F.; Devlieghere, F. Application of Bioplastics for Food Packaging. *Trends Food Sci. Technol.* **2013**, *32*, 128–141. [CrossRef]
231. EPA Reducing Wasted Food & Packaging: A Guide for Food Services and Restaurants. Available online: https://www.epa.gov/sites/default/files/2015-08/documents/reducing_wasted_food_pkg_tool.pdf (accessed on 14 January 2023).
232. Eurostat Packaging Waste Statistics. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Packaging_waste_statistics (accessed on 10 December 2022).
233. European Comission. *Regulation of the European Parliament and of the Council on Packaging and Packaging Waste, Amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and Repealing Directive 94/62/EC*; European Comission: Brussels, Belgium, 2020.
234. Dörnyei, K.R.; Bauer, A.; Krauter, V.; Herbes, C. (Not) Communicating the Environmental Friendliness of Food Packaging to Consumers—An Attribute- and Cue-Based Concept and Its Application. *Foods* **2022**, *11*, 1371. [CrossRef]
235. Herbes, C.; Beuthner, C.; Ramme, I. How Green Is Your Packaging—A Comparative International Study of Cues Consumers Use to Recognize Environmentally Friendly Packaging. *Int. J. Consum. Stud.* **2020**, *29*, 258–271. [CrossRef]
236. Testa, F.; Iovino, R.; Iraldo, F. The Circular Economy and Consumer Behaviour: The Mediating Role of Information Seeking in Buying Circular Packaging. *Bus. Strategy Environ.* **2020**, *29*, 3435–3448. [CrossRef]
237. United Nations Development Programme. *The Sustainable Development Goals*; United Nations Development Programme (UNDP): New York, NY, USA, 2015.
238. *ASTM:D6400-22*; Standard Specification for Labeling of Plastics Designed to Be Aerobically Composted in Municipal or Industrial Facilities. ASTM: West Conshohocken, PA, USA, 2022.
239. *ASTM:D5388-15*; Biodegradation Test-Composting. ASTM: West Conshohocken, PA, USA, 2021.
240. López-ibáñez, S.; Beiras, R. Science of the Total Environment Is a Compostable Plastic Biodegradable in the Sea ? *A Rapid Standard Protocol to Test Mineralization in Marine Conditions.* **2022**, *831*, 154860. [CrossRef]
241. Guiné, R.P.F.; Bartkiene, E.; Florença, S.G.; Djekić, I.; Bizjak, M.Č.; Tarcea, M.; Leal, M.; Ferreira, V.; Rumbak, I.; Orfanos, P.; et al. Environmental Issues as Drivers for Food Choice: Study from a Multinational Framework. *Sustainability* **2021**, *13*, 2869. [CrossRef]
242. Macena, M.W.; Carvalho, R.; Cruz-Lopes, L.P.; Guiné, R.P.F. Plastic Food Packaging: Perceptions and Attitudes of Portuguese Consumers about Environmental Impact and Recycling. *Sustainability* **2021**, *13*, 9953. [CrossRef]
243. Ipsos Consumers Want Brands to Help Them Reduce Their Waste. Available online: https://www.ipsos.com/en-us/news-polls/Consumers-want-brands-to-help-them-reduce-their-waste (accessed on 19 November 2022).
244. United Nations Development Programme. *Peoples' Climate Vote*; United Nations Development Programme (UNDP): New York, NY, USA, 2021.
245. The Coca-Cola Company Sprite Switching from Green to Clear PET Bottles in Southeast Asia. Available online: https://www.coca-colacompany.com/press-releases/sprite-switching-to-clear-pet-bottles-in-southeast-asia (accessed on 18 November 2022).
246. Packaging Europe On-the-Go Cup Recycling Scheme Launched by McDonald's and Costa. Available online: https://packagingeurope.com/news/on-the-go-cup-recycling-scheme-launched-by-mcdonalds-and-costa/8492.article (accessed on 18 November 2022).
247. Danone, S.A. Ellen MacArthur Foundation. Available online: https://ellenmacarthurfoundation.org/global-commitment-2021/signatory-reports/ppu/danone-sa (accessed on 30 November 2022).
248. PepsiCo Europe PepsiCo Europe Sets Ambition to Eliminate Virgin Fossil-Based Plastic in all of Its Crisp and Chip Bags by the End of the Decade. Available online: https://www.pepsico.com/our-stories/press-release/pepsico-europe-sets-ambition-to-eliminate-virgin-fossil-based-plastic-in-all-of-its-crisp-and-chip-bags-by-the-end-of-the-decade (accessed on 18 November 2022).
249. Unilever We're Introducing Paper Tubs for Our Carte D'or Ice Cream. Available online: https://www.unilever.com/news/news-search/2022/were-introducing-paper-tubs-for-our-carte-dor-ice-cream/ (accessed on 18 November 2022).
250. The Kraft Heinz Company. Developing and Testing Recyclable Fiber-Based Microwavable Cup. Available online: https://news.kraftheinzcompany.com/press-releases-details/2021/Kraft-Mac--Cheese-Developing-and-Testing-Its-First-Recyclable-Fiber-Based-Microwavable-Cup/default.aspx (accessed on 18 November 2022).

251. The Kraft Heinz Company. Shake ' N Bake to Save 900, 000 Pounds of Plastic Waste Annually with Brand 's First-Ever Packaging Update. Available online: https://news.kraftheinzcompany.com/press-releases-details/2022/Shake-N-Bake-to-Save-900000-Pounds-of-Plastic-Waste-Annually-with-Brands-First-Ever-Packaging-Update/default.aspx (accessed on 18 November 2022).
252. Mondelez International Our Commitment To 100% Recyclable Packaging. Available online: https://www.mondelezinternational.com/News/100-Recyclable-Packaging (accessed on 18 November 2022).
253. News, F.B. Food Business News. Available online: https://www.foodbusinessnews.net/articles/15229-nestle-investing-2-billion-in-sustainable-packaging-innovation (accessed on 30 November 2022).
254. Tesco PLC Tesco Engages Suppliers to Accelerate Plans to Tackle Plastic Waste. Available online: https://www.tescoplc.com/news/2022/tesco-engages-suppliers-to-accelerate-plans-to-tackle-plastic-waste/ (accessed on 18 November 2022).
255. Starbucks Starbucks to Eliminate Plastic Straws Globally by 2020. Available online: https://news.starbucks.com/press-releases/starbucks-to-eliminate-plastic-straws-globally-by-2020 (accessed on 18 November 2022).
256. Bacardi Limited Bacardi Cuts Plastic in Packaging. Available online: https://www.bacardilimited.com/media/news-archive/bacardi-cuts-plastic-in-packaging/ (accessed on 18 November 2022).
257. G.A. Circular Accelerating the Circular Economy for Post-Consumer PET Bottles in Southeast Asia. Available online: https://www.gacircular.com/full-circle/ (accessed on 24 November 2022).
258. Ligthart, T.N.; Ansems, T.A.M.M. Modelling of Recycling in LCA. *Post-Consum. Waste Recycl. Optim. Prod.* **2012**, 185–210. [CrossRef]
259. *ISO 14044:2006*; Environmental Management—Life Cycle Assessment—Principles and Framework. International Organization for Standardization: Genève, Switzerland, 2006.
260. Pauer, E.; Wohner, B.; Heinrich, V.; Tacker, M. Assessing the Environmental Sustainability of Food Packaging: An Extended Life Cycle Assessment Including Packaging-Related Food Losses and Waste and Circularity Assessment. *Sustainability* **2019**, *11*, 925. [CrossRef]
261. Siracusa, V.; Ingrao, C.; Lo Giudice, A.; Mbohwa, C.; Dalla Rosa, M. Environmental Assessment of a Multilayer Polymer Bag for Food Packaging and Preservation: An LCA Approach. *Food Res. Int.* **2014**, *62*, 151–161. [CrossRef]
262. Toniolo, S.; Mazzi, A.; Niero, M.; Zuliani, F.; Scipioni, A. Comparative LCA to Evaluate How Much Recycling Is Environmentally Favourable for Food Packaging. *Resour. Conserv. Recycl.* **2013**, *77*, 61–68. [CrossRef]
263. Wender, B.A.; Foley, R.W.; Prado-Lopez, V.; Ravikumar, D.; Eisenberg, D.A.; Hottle, T.A.; Sadowski, J.; Flanagan, W.P.; Fisher, A.; Laurin, L.; et al. Illustrating Anticipatory Life Cycle Assessment for Emerging Photovoltaic Technologies. *Environ. Sci. Technol.* **2014**, *48*, 10531–10538. [CrossRef]
264. Bezergianni, S.; Chrysikou, L.P. Application of Life-Cycle Assessment in Biorefineries. In *Waste Biorefinery: Integrating Biorefineries for Waste Valorisation*; Bhaskar, T., Rene, E.R., Pandey, A., Tsang, D.C.w., Eds.; Elsevier B.V.: Amsterdam, The Netherlands, 2020; pp. 455–480. ISBN 9780128182284.
265. Elginoz, N.; Khatami, K.; Owusu-Agyeman, I.; Cetecioglu, Z. Life Cycle Assessment of an Innovative Food Waste Management System. *Front. Sustain. Food Syst.* **2020**, *4*, 1–9. [CrossRef]
266. Leceta, I.; Etxabide, A.; Cabezudo, S.; de la Caba, K.; Guerrero, P. Bio-Based Films Prepared with by-Products and Wastes: Environmental Assessment. *J. Clean. Prod.* **2014**, *64*, 218–227. [CrossRef]
267. Günkaya, Z.; Banar, M. An Environmental Comparison of Biocomposite Film Based on Orange Peel-Derived Pectin Jelly-Corn Starch and LDPE Film: LCA and Biodegradability. *Int. J. Life Cycle Assess.* **2016**, *21*, 465–475. [CrossRef]
268. Kyriakopoulou, K.; Papadaki, S.; Krokida, M. Life Cycle Analysis of β-Carotene Extraction Techniques. *J. Food Eng.* **2015**, *167*, 51–58. [CrossRef]
269. Papadaki, S.; Kyriakopoulou, K.; Tzovenis, I.; Krokida, M. Environmental Impact of Phycocyanin Recovery from Spirulina Platensis Cyanobacterium. *Innov. Food Sci. Emerg. Technol.* **2017**, *44*, 217–223. [CrossRef]
270. Rajesh Banu, J.; Preethi; Kavitha, S.; Gunasekaran, M.; Kumar, G. Microalgae Based Biorefinery Promoting Circular Bioeconomy-Techno Economic and Life-Cycle Analysis. *Bioresour. Technol.* **2020**, *302*, 122822. [CrossRef]
271. Dilkes-Hoffman, L.S.; Lane, J.L.; Grant, T.; Pratt, S.; Lant, P.A.; Laycock, B. Environmental Impact of Biodegradable Food Packaging When Considering Food Waste. *J. Clean. Prod.* **2018**, *180*, 325–334. [CrossRef]
272. Lam, C.; Yu, I.K.M.; Hsu, S.; Tsang, D.C.W. Life-Cycle Assessment on Food Waste Valorisation to Value-Added Products. *J. Clean. Prod.* **2018**, *199*, 840–848. [CrossRef]
273. Croxatto Vega, G.; Sohn, J.; Voogt, J.; Birkved, M.; Olsen, S.I.; Nilsson, A.E. Insights from Combining Techno-Economic and Life Cycle Assessment—A Case Study of Polyphenol Extraction from Red Wine Pomace. *Resour. Conserv. Recycl.* **2021**, *167*, 105318. [CrossRef]
274. Gullón, P.; Gullón, B.; Dávila, I.; Labidi, J.; Gonzalez-Garcia, S. Comparative environmental Life Cycle Assessment of integral revalorization of vine shoots from a biorefinery perspective. *Sci. Total Environ.* **2018**, *624*, 225–240. [CrossRef]
275. Gonzalez-Garcia, S.; Gullón, B.; Moreira, M.T. Environmental Assessment of Biorefinery Processes for the Valorization of Lignocellulosic Wastes into Oligosaccharides. *J. Clean. Prod.* **2018**, *172*, 4066–4073. [CrossRef]
276. Santiago, B.; Arias Calvo, A.; Gullón, B.; Feijoo, G.; Moreira, M.T.; González-García, S. Production of Flavonol Quercetin and Fructooligosaccharides from Onion (Allium Cepa L.) Waste: An Environmental Life Cycle Approach. *Chem. Eng. J.* **2020**, *392*, 123772. [CrossRef]

277. Rodríguez-Meizoso, I.; Castro-Puyana, M.; Börjesson, P.; Mendiola, J.A.; Turner, C.; Ibáñez, E. Life Cycle Assessment of Green Pilot-Scale Extraction Processes to Obtain Potent Antioxidants from Rosemary Leaves. *J. Supercrit. Fluids* **2012**, *72*, 205–212. [CrossRef]
278. Piccinno, F.; Hischier, R.; Seeger, S.; Som, C. Life Cycle Assessment of a New Technology to Extract, Functionalize and Orient Cellulose Nanofibers from Food Waste. *ACS Sustain. Chem. Eng.* **2015**, *3*, 1047–1055. [CrossRef]
279. do Nascimento, D.M.; Dias, A.F.; de Araújo Junior, C.P.; de Freitas Rosa, M.; Morais, J.P.S.; de Figueirêdo, M.C.B. A Comprehensive Approach for Obtaining Cellulose Nanocrystal from Coconut Fiber. Part II: Environmental Assessment of Technological Pathways. *Ind. Crops Prod.* **2016**, *93*, 58–65. [CrossRef]
280. Vauchel, P.; Colli, C.; Pradal, D.; Philippot, M.; Decossin, S.; Dhulster, P.; Dimitrov, K. Comparative LCA of Ultrasound-Assisted Extraction of Polyphenols from Chicory Grounds under Different Operational Conditions. *J. Clean. Prod.* **2018**, *196*, 1116–1123. [CrossRef]
281. Frascari, D.; Molina Bacca, A.E.; Wardenaar, T.; Oertlé, E.; Pinelli, D. Continuous Flow Adsorption of Phenolic Compounds from Olive Mill Wastewater with Resin XAD16N: Life Cycle Assessment, Cost–Benefit Analysis and Process Optimization. *J. Chem. Technol. Biotechnol.* **2019**, *94*, 1968–1981. [CrossRef]
282. Garcia-Garcia, G.; Rahimifard, S.; Matharu, A.S.; Dugmore, T.I.J. Life-Cycle Assessment of Microwave-Assisted Pectin Extraction at Pilot Scale. *ACS Sustain. Chem. Eng.* **2019**, *7*, 5167–5175. [CrossRef]
283. Kothari, R.; Pandey, A.; Ahmad, S.; Kumar, A.; Pathak, V.V.; Tyagi, V.V. Microalgal Cultivation for Value-Added Products: A Critical Enviro-Economical Assessment. *3 Biotech* **2017**, *7*, 1–5. [CrossRef]
284. Ingrao, C.; Gigli, M.; Siracusa, V. An Attributional Life Cycle Assessment Application Experience to Highlight Environmental Hotspots in the Production of Foamy Polylactic Acid Trays for Fresh-Food Packaging Usage. *J. Clean. Prod.* **2017**, *150*, 93–103. [CrossRef]
285. Tetra Pak LCA Examples Investigating Environmental Impact of Food Packaging. Available online: https://www.tetrapak.com/sustainability/planet/environmental-impact/a-value-chain-approach/life-cycle-assessment/lca-examples (accessed on 4 December 2022).
286. Billerud How to Perform a Life Cycle Assessment of Packaging. Available online: https://www.billerudkorsnas.com/managed-packaging/knowledge-center/articles/how-to-perform-a-life-cycle-assessment-of-packaging (accessed on 18 December 2022).
287. Coffigniez, F.; Matar, C.; Gaucel, S.; Gontard, N.; Guilbert, S.; Guillard, V. The Use of Modeling Tools to Better Evaluate the Packaging Benefice on Our Environment. *Front. Sustain. Food Syst.* **2021**, *5*, 38. [CrossRef]
288. Corrado, S.; Ardente, F.; Sala, S.; Saouter, E. Modelling of Food Loss within Life Cycle Assessment: From Current Practice towards a Systematisation. *J. Clean. Prod.* **2017**, *140*, 847–859. [CrossRef]
289. Omolayo, Y.; Feingold, B.J.; Neff, R.A.; Romeiko, X.X. Life Cycle Assessment of Food Loss and Waste in the Food Supply Chain. *Resour. Conserv. Recycl.* **2021**, *164*, 105119. [CrossRef]