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Edible films and coatings based on agrifood residues: a new trend in the food packaging research

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Food packaging trends have been changing in the last years, mainly due to consumer concerns about plastic pollution and agrifood waste. Recent advances in the development of edible films and coatings are discussed. These systems can be much more than packaging, with additional functions such as antioxidant, antimicrobial, and nutritional properties, among others. Challenges in industrial processes and/or in some films' properties are addressed from the authors' point of view. The use of agrifood residues in these packaging systems is included as a promising strategy that promotes sustainability and circular economy. The authors consider that more research and actions are needed to achieve the best packaging material for each food product with reduced production costs.

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Introduction

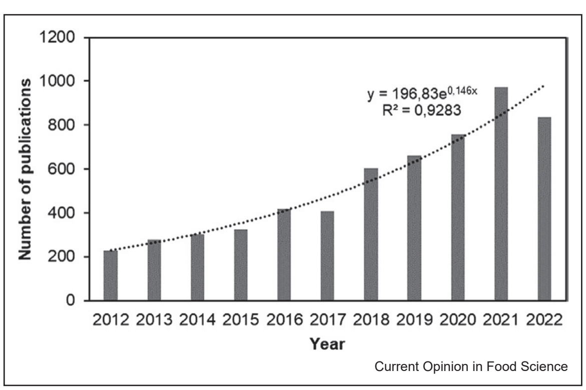
Packaging is essential to preserve the properties of food and drinks. Among other functions, it is mainly needed to maintain food safety, protect food against microbial contaminations, prevent the waste or loss of food, and improve food shelf life but also to give information to consumers about the product [1–4]. Food products have always been packaged in a varied selection of materials, including papers, glass, metals, and plastics (e.g. polyethylene, polypropylene, and polyethylene terephthalate) [5]. Properties of plastics, such as low production costs, durability, good mechanical properties, and resistance to oil and chemicals, are responsible for their wide use in the food packaging industry [6,7]. However, the main source of global plastic pollution comes from food and drink packaging. Efforts have recently been made by researchers, governments, and companies to address this situation in order to reduce the impact of plastic pollution in the environment. These actions include policies and regulations from the European Commission, as well as other commitments and pacts [8–10]. Nevertheless, recent studies have shown that the transition from petroleum-based packaging to sustainable alternatives in this sector is slow and inconsistent. Actually, companies have the tendency to collect and recycle plastic, rather than replace it by sustainable packaging solutions [11,12]. Therefore, the authors consider that more investment, actions, commitments, and even incentives have to be available to research institutions and companies to accelerate the transition from conventional to environmentally friendly packaging systems. Moreover, it would be a good strategy to promote agreements/projects between companies and the academy/research centers, in order to join efforts to reach the best packaging solutions faster [13,14]. Bioplastics, and other innovative solutions such as edible films and coatings, have been investigated to replace traditional packaging systems. Bioplastics have this designation because they act as plastic polymers and may be classified as biodegradable polymers or bio-based plastics [7]. Some examples of bioplastics include polybutylene succinate, polylactic acid, polybutylene adipate terephthalate, and polyhydroxyalkanoate [3,7]. Its market is increasing but they are more expensive to produce than conventional plastics and there are some compatibility problems with other materials in the recycling flows [7]. Nevertheless, bioplastics may be produced with the machinery already existent in plant industries, which is a clear advantage over biopolymers. The use of biopolymers is also increasing in the food packaging area, and consumers are raising their interest in natural and sustainable products. Such raw materials include macronutrients and are usually in the form of films or coatings [3,14]. Producing edible biopolymers, such as starch and gelatine, to prepare 'bioplastics' is not economically viable, in addition, this kind of 'bioplastic' production is not feasible with the existing equipment in plastic packaging industries [7]. Alternatively, such biopolymers may be extracted from agro-industrial residues as sources of valuable materials to be used for the films/coatings production, being fully used in the food chain. Considering the increasing importance of these systems, the authors focused on edible films and coatings, in particular those obtained from food residues, in the last two years.

Edible films and coatings: an increasing trend with benefits and challenges

Nowadays, the concept of packaging has changed in a way that the packaging systems may not be just packaging materials and include other functions such as antioxidant activity, antimicrobial properties, or oxygen-scavenging, and presence of sensors, converting the conventional packaging into active and/or intelligent packaging, and being some of them edible films/coatings [15–18]. A film is usually considered as a thin standalone solid sheet manufacturing using at least one processing technique, and it is then applied and used to wrap or contain food products. On the other side, a coating is applied directly to the food product surface in its liquid form, and using methods such as dipping, spraying, or brushing [19]. The authors would like to clarify that sometimes the term 'film' is also used for coatings, since the film formation is made *in situ*, coating the food product surface.

The research area of 'edible films/coatings' has increased exponentially in the last years, as depicted in Figure 1. The search was limited up to the last ten years using the online database SCOPUS with descriptors 'edible' and 'coatings' or 'films'. As can be observed, the number of publications in this topic is currently about five times higher than in 2012. If we consider only the last years (the period between 2020 and 2022), the number of publications is almost 50% of all published literature in the last ten years. Nevertheless, edible films and coatings have been used for centuries to protect food and extend their shelf life. Some examples include the wax or lard applied in fruits, vegetables, meat, and fish [15,20]. Moreover, there are some specific applications of edible films that have been explored by researchers, in recent years, that are related to the use of edible films as packaging systems. These include soluble sachets made of soybean polysaccharide and gelatine, for soups or beverages (to be solubilized in water) [21]. Other examples include edible wraps made by gelatine–pectin and used to decrease the moisture content of ricotta cheese [22]. Also, the primary packaging of individual candies may be replaced with edible films [20].

Figure 1



Number of publications in the last ten years, considering the descriptors 'edible' AND 'coatings' OR 'films', searched on SCOPUS, on October 13th, 2022.

Clear advantages have been reported for these biopolymeric systems, since they serve as a barrier between food and the surrounding environment, are biodegradable, and nontoxic. They usually improve food quality by inhibiting the microorganism growth (e.g. intrinsic antimicrobial activity of chitosan and plant extracts) and also by preventing the oxidation phenomenon (e.g. green tea extract to preserve fresh sausage) [23–26]. Edible films and coatings also improve nutritional value of food products as well as their shelf life [27,28]. Recently, some researchers have studied the effect of zein-based edible films and coatings for extending wheat bread shelf life, and they found that the incorporation of sunflower extract decreased the water vapor permeability and promoted a plasticizing effect [29]. Others have reviewed two important natural polymers, chitosan and alginate, and discussed the functionality of edible coatings and films based on these two polymers, to increase shelf life of fruit and vegetables [30]. Also, to preserve this type of food products, pectin-based coatings have demonstrated advantages since they act as a barrier on the surface of fruits and vegetables, allowing a better moisture and water retention [31]. The incorporation of prebiotics and probiotics in edible films/coatings is another strategy that has been recently evaluated as a means of improving health [32–34]. One example was the development of edible films containing sodium alginate and chitosan with probiotics that showed the ability to preserve cheese from spoilage [34].

Despite all advantages and promising properties of edible films and coatings based on natural polymers, the authors would like to point out some disadvantages and challenges that usually impair their arrival to the market. The authors are concerned about the nontoxicity concept that is usually associated with edible films/coatings based on natural sources. There are many works that evaluate the biological activities of edible films/coatings but fail in studying their cytotoxicity. This evaluation should be implemented in all studies since an apparent safe material may turn into a toxic substance due to reactions or to the excessive concentration in the formulation. Natural compounds can also be toxic.

Moreover, edible films usually have limited mechanical and barrier properties, limiting their use as a real package. However, efforts have been made to manage these properties by using multilayers or resorting to nanotechnology [27,30,35]. Their hydrophilic nature is also a challenging point [36], but the researcher community has been working on this issue by adding other components in these films to be competitive in the current market. In particularly, the use of lipophilic compounds, such as some essential oils (e.g. thyme, lemon, and oregano essential oils), may be incorporated in polysaccharide- and protein-based films to improve moisture barrier, as already reviewed [27]. Moreover, these oils present antimicrobial properties and so on. In a very recent work, some authors have studied the chitosan–gelatine active coating, loaded with lemongrass oil, as an antimicrobial compound, and they found that the coating formulation on cherry tomato samples (assessed by predictive kinetic models and digital imaging) was very effective since fungal contamination was not observed for 20 days [37]. Other researchers have tested the addition of curcumin in biodegradable films made by chitosan and cellulose and observed that the curcumin addition increased the hydrophobicity and oxygen permeability of the film [38]. Nevertheless, when lipophilic compounds are used in films of hydrophilic nature, the use of emulsifiers/plasticizers (e.g. glycerol and polysorbate) is needed to avoid separation of phases between them and to improve films' flexibility. In addition to essential oils, many waxes have been used to coat food products, in particular fruits, including candelilla, carnauba, and beeswax to prevent fungal growth and extend shelf life [27,39].

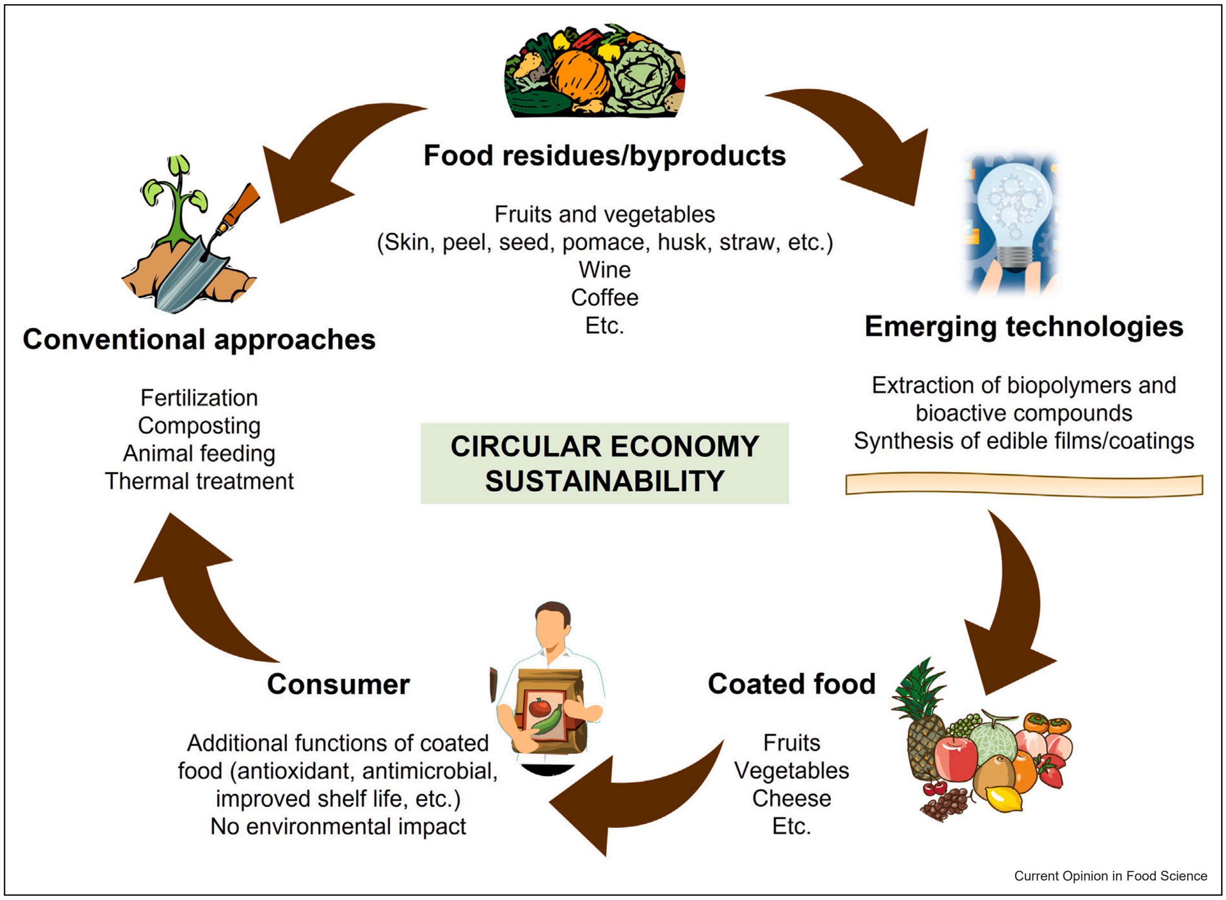
Some companies have followed the research and consumers trends and have already developed some coatings and films to be applied in food products, namely fruits, vegetables, cheeses, among others. The list is not long, and includes a dozen of companies from France, Portugal, United Kingdom, Netherlands, and the United States. This is clearly an area that is starting to grow at the commercial level, and it is expected to expand in the next years [27]. From the authors' point of view, the usual production of films by solvent casting, that is, biopolymer dissolution followed by a drying step, may be a drawback of these materials due to the difficulty of conventional packaging industries in the processes/equipment adaptation. It would require optimization procedures and money investment to scale up the process to obtain this type of packaging solutions. Despite the low temperatures that are usually applied in the film casting method, long drying times are needed, impairing its use for commercial applications. The hot melt extrusion is another method that can be used to obtain edible films, but high temperatures are needed since the polymer/material melting is necessary to obtain the film [27]. Therefore, only polymers that tolerate heat and are thermoplastic may be used in this process (e.g. bioplastics). Regarding coatings, they are usually applied by dipping, spraying, brushing, as well as panning and fluidized bed processing techniques [19,27,40], and viscosity of solutions is an important factor to take into consideration.

The potential of agrifood residues

About 1/3 of all produced food is wasted or lost, which means more than 1 billion ton per year, according to Food and Agriculture Organization of the United States [41]. In this review, we have already discussed the importance of innovative food packaging systems to preserve food for longer and consequently to reduce food waste. Another possibility to reduce food waste is by their valorization through many strategies. Fruit and vegetable wastes constitute a crucial source to achieve important natural products and bioactive compounds. There are some conventional approaches related to agrifood residue management that include animal feeding, landfilling, composting, and thermal treatment. However, nowadays, emerging technologies such as the extraction of biopolymers and bioactive compounds, and synthesis of bioplastics and edible films [42], must be considered to attain an integral management of these residues/by-products (Figure 2). It should be noted that the terms waste, residue, and by-product are sometimes used interchangeably. Despite controversial definitions, the authors consider that by-products have significant market value, while wastes and residues have no value or they have not yet been explored and are typically discarded. Nevertheless, in this review, all these terms are used to refer to materials that can be valorized, namely for food packaging applications.

In recent years, many researchers have focused their attention on specific food by-products/residues that have potential to be applied as components of biodegradable and edible films for fruit and vegetable preservation but also for meat, fish, and derived products [43]. Distinct parts of plants, which are usually seen as residues, including skin, peel, seed, pomace, husk, and straw, among others, are rich in polymers such as polysaccharides and proteins, the main raw materials employed in edible film production. The presence of other molecules, namely phenolic compounds, is also well-known and responsible for antioxidant, anti-inflammatory, and other activities [44]. These bioactive compounds will improve functions of packaging materials and nutrition of consumers, in the case of edible films/coatings. The authors have already investigated the potential of several food residues such as different forms

Figure 2



Schematic representation of food chain of biodegradable edible films/coatings based of food residues.

of tomato waste (rotten tomato, green tomato, and tomato branches), and they found these residues are rich in phenolic compounds and antioxidant activity, as well as flavoring compounds, being interesting sources to be incorporated in edible films/coatings [45,46]. Also, cellulose and lignin obtained from food and forestry residues may be applied in the packaging sector to reinforce biodegradable films, as recently studied by the authors [47], and reviewed elsewhere [48]. Other authors have used pumpkin wastes to extract protein and pectin, used then as film-forming materials [49]. Recently, other researchers have used an extract from a winery solid by-product in poly(vinyl alcohol)/gelatin films and observed that the extract improved the flexibility of the films as well as the antioxidant activity [50]. The potential use of mung bean protein and pomegranate peel of food industry to develop edible films for packaging of food products has been also explored in a recent work [51]. Peel potato is used to form edible films and the addition of curcumin in these films showed significant reduction of lipid oxidation in the fresh pork during storage [52]. Antioxidant activity was also observed for chitosan films loaded with banana peel extracts to be applied as coating in apples [53]. Fibers from mushroom by-products have been recently investigated to be used in edible films and film properties were improved [54].

Several residues from fruits, vegetables, and other natural sources (e.g. mango, pomegranate, grape, citrus, apple, berries, rice, coffee, etc.) have been investigated and recently reviewed [44]. Despite their promising use in the food packaging industry, the authors have the opinion that the heterogeneity of each food residue batch is a huge challenge that has to be carefully addressed, namely by analyzing its composition and hygiene/safety in a suitable and cost-effective way. The authors consider there is a lack of a standard procedure that may be applied to prepare and characterize distinct food residues, in order to use them efficiently in the film/coating production.

Conclusions and future perspectives

Food packaging is an area in constant development and the consumer demands have been changing over the last years, being the natural-based and sustainable materials the preferential choice.

Food residues are a valuable source of polymers, namely proteins and polysaccharides, as well as bioactive molecules, which can be valorized and used in edible films and coatings. These systems have been explored and characterized, presenting many advantages such as biodegradability, antioxidant and antimicrobial activity, and nutritional benefits. However, taking into account the associated challenges, the authors consider additional efforts to normalize or categorize the residues and scaling up the production of these systems are still needed.

Edible films/coatings based on food residues are promising systems for food packaging, but more research and incentives are needed to achieve the best solution, in an environmental and economic sustainable way.

Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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