The use of biowaste for the production of biodegradable superabsorbent materials

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ABSTRACT

Climate Change, the large accumulation of waste, the generation of microplastics and the recent scarcity of raw materials are some of the problems that have led to a radical change in the conception of economy from a linear system to a circular system. Thus, different policies, such as Green Deal of the European Union or Horizon Europe, have been created on these aspects. In this context, the use of biowaste for the production of superabsorbent materials can be a clear example of how circular economy can be applied. This opinion review aims to be a global view of these initiatives, presenting examples of the use of different biowaste in superabsorbent materials and explaining the deficiencies that have prevented their inclusion in the market. This review shows that, although the use of biowaste seems to be a key factor for change, further research is needed to make the products more competitive in the current market.

Keywords: Biodegradable; Bioplastic; Biowaste; Superabsorbent materials.

1. INTRODUCTION

In the current economy model, the so-called linear economy predominates. This model is based on production under the guidelines of buying, consuming and discarding. This model generates a large amount of waste of different types that make proper management and treatment difficult, polluting and stressing the planet's ability to renew or produce new resources [1]. This linear economy is based on the false assumption that natural resources will always be available, abundant, easy to obtain and cheap to dispose of, usually by burying or burning. The serious environmental problem has shown that this model is completely unsustainable, having a great impact on resources and ecosystems [2]. In addition, this impact is aggravated by current consumption habits, increasingly associated with "fast fashion": renewing goods before their useful life cycle is exhausted [3].

The annual global demand for resources is 1.75 times the capacity of the planet [4]. In other words, the Earth cannot continue with the usual rate of consumption, and this situation is aggravated by pollution. Therefore, it is necessary to rethink the linear economy system. An emerging alternative is known as the circular economy. The objective of this strategy, which aims to transform the economy and productivity, is to maintain the value of products, materials and resources in the economy for as long as possible while minimizing the generation of waste [5]. In this way, it has three key principles: preserve and improve natural capital, optimize the use of resources and promote the efficiency of the system [6]. In other words, closing the loop.

This circular economy will improve economic performance while reducing resource use, identify and create new opportunities for economic growth via innovation and minimize the environmental impacts of the use of resources [7]. The transition from linear to circular economy looks increasingly encouraging. Thus, different administrations and companies are carrying out several actions to promote circular economy, being reflected in different initiatives and plans.

Biomass seems to be a potential raw material for replacing polymers synthesized from oil in applications such as superabsorbent materials. The world consumption of biomass, fossil fuels, metals and minerals is extremely high, producing a large amount of waste (70% of production, 2,14 billon tons per year) [8]. All of this is unsustainable, so new clean and innovative technologies and products are being developed and promoted.

The new Green Deal of the European Union (2019-2023) emphasizes an immediate action to make Europe a climate-neutral region in 2050. Together, the new EU Research and Innovation Programme: Horizon Europe (2021-2027) tackles Climate Change, helps to achieve Sustainable Development Goals and boosts the EU's competitiveness and growth. In this way, a circular economy is a precondition for achieving the desired climate neutrality and halting the loss of biodiversity.

In this context, the main objective of this review is to provide an overview of the use of this philosophy in superabsorbent materials. Thus, the results obtained in the last two years (2020-2022) on the use of biowaste as superabsorbent materials will be discussed. This study is important for food science since perishable fresh products such as meat and fish often present transportation and packaging problems due to water condensation on the products (generated by changes in temperature in the packaging) that directly affects the quality and expiration date. These problems have been remedied using packaging trays that include superabsorbent materials.

2. BIOWASTE

Biowaste is known as any biodegradable organic waste of vegetable and/or animal origin, susceptible to biological degradation, and generated in the home and commercial environment, normally agri-food industries [9]. These biowastes have great variability, although their largest proportion is made up of organic matter, such as proteins, polysaccharides, lipids, fibers or water [10]. The main environmental threat from biowaste is the production of methane from its decomposition in landfills, which accounted for around 4.6% of total greenhouse gas emissions in 2021 [11]. All this generates an environmental problem that must be solved.

In this way, alternative strategies and technologies have been created in line with the European Green Deal and the EU bioeconomy strategy. Thus, the valorization of these biowastes or by-products has been investigated for the development of sustainable bioproducts. Therefore, there is a growing interest in the maximum recovery and valorization of the resources offered by the food industry. In agri-food and forestry processes, billions of tons of biowaste are generated globally throughout the entire production chain, which is expected to increase in the coming years due to globalization [12]. However, the potential value of this biowaste is high, so the use of this discarded material in biobased applications could be economically viable and favorable for the environment [13].

3. SUPERABSORBENT MATERIALS

Superabsorbent materials (SAP) are made up of a hydrophilic polymeric network with the capacity to absorb and retain water without dissolving, undergoing a notable volume expansion [14]. A material is considered superabsorbent if its absorption capacity exceeds 10 times its weight; some materials have exceeded 1000 times its weight. Synthetic polymers derived from acrylic acid and acrylamide dominate the market for SAP [15]. However, these types of materials present toxicity and low biodegradability problems [16], apart from coming from non-renewable sources and having a high price [17]. There are also some synthetic polymers that are used as SAPs but have a higher biodegradable character. Some examples of it are materials based on PLA [18] and PVA [19]. Nevertheless, it is necessary to find more sustainable plastic substitutes, based on raw materials of natural and renewable origin, with greater cost efficiency and lower environmental impact. However, the market for polymeric materials based on raw materials of natural and renewable origin with good biocompatibility and biodegradability is still quite limited [20].

Among the materials of natural origin, those based on polysaccharides and proteins stand out [21]. Polysaccharides have been more thoroughly studied, especially those derived from cellulose. However, their high cost hinders the replacement of acrylic superabsorbent materials. In addition, other polysaccharides with good potential based on chitin, starch, xanthan gum, etc., have also been studied, but require prior copolymerization treatment with a vinyl or acrylonitrile monomer. In addition, their effectiveness is lower than the synthetic superabsorbent materials and their technology is not sufficiently developed [22,23].

The production of biodegradable superabsorbent materials (SAB), such as those based on proteins, has technological, economic and environmental benefits [24]. Thus, there is great potential to modulate their properties due to their great variability in amino acid composition, the wide range of potential formulations and the great variety of applicable processing techniques. On the other hand, proteins are the most undervalued raw material concerning to their industrial applications; therefore, their use in this type of material implies a high added value [25]. However, the development of protein-based superabsorbent materials, capable of competing with commercial ones, requires investigating new formulation and processing alternatives, and validating their behavior in technological applications.

Biowaste is a relatively cheap and undervalued alternative for the formation of these SABs. Most of them have large amounts of proteins and polysaccharides in their composition that can form the biopolymeric framework of the materials [26]. In addition, its use in this type of material can generate not only an economic benefit but also an environmental benefit [27]. Thus, the circular economy of this waste is promoted and the food safety problem is prevented by using proteins and polysaccharides that are not viable for human consumption.

3.1 Biowastes as raw materials for SAB

Biowastes must have strongly hydrophilic groups in their chemical composition in order to be considered potential raw materials for the development of superabsorbent materials. These polar groups can create hydrogen bonds with water, such as -OH or -COOH [28]. Carboxyl groups predominate in polysaccharides, while amines and amides are found in proteins. Table 1 shows the different biowastes used to process superabsorbent materials. As can be seen, polysaccharides have been more thoroughly investigated than proteins. In this way, it has been possible to achieve a higher water absorption capacity in polysaccharide-based materials (600-3000% in polysaccharide materials vs. 100-3000% in protein/additive ones) [29]. Nevertheless, the additives that they need could compromise their biodegradability and cost.

Table 1: Different biowastes used as raw materials for superabsorbent materials.

Biopolymer	**Raw material**	**Biowaste origin**	**Optional additives**	**Water absorption at 24 h (%)**	**Ref.**
Polysaccharides	Starch	Fruit and vegetable discards	Urea	600-2000	[30,31]
	Sodium alginate	Algae, seaweed	Carboxymethylchitosan / quaternized chitosan / poly(acrylic acid)	500-3000	[32–34]
	Chitosan	mushrooms, shrimp shells and crustaceans	Carboxymethyl starch / Curdlan	900-2000	[35,36]
	Cellulose	-	-	680-900	[37,38]
Lignin		Pulp	Polyethylene glycol	100-2000	[39,40]
Proteins	Whey / Wheat gluten	Quality and sanity discards	Ethylenediaminetetraacetic dianhydride (EDTAD)	100-800	[41–43]
	Casein	-	Genipin	100-150	[44]
	Soy	Soy oil production	2,2',2'',2'''-(Ethane-1,2-diyldinitrilo)tetraacetic acid (EDTA)	1000-3000	[45]
	Pea	Quality discards	-	200-500	[46]
	Porcine plasma	Porcine industry	Glutaraldehyde	100-3500	[47]

The most used proteins were chosen due to their high content of glutamic acid, lysine or aspartic acid, which are the most hydrophilic amino acids [48]. Nevertheless, they cannot achieve a competitive water uptake capacity if no additional materials are added. These additional materials can create problems due to the higher carbon footprint that the final products can have. In this sense, it is necessary to reflect on the purpose of these products, since using a natural and biodegradable product is not always convenient if its life cycle harms the environment more than a synthetic material.

Therefore, to date, polysaccharides seem to be the most promising for creating high-capacity superabsorbent materials. However, proteins can be used where superabsorbent requirements are not as great (eg. wipes). In this way, it is important to know the properties desired in the final product before choosing the raw material to be used, always obtaining the one that meets the essential requirements with a lower economic and environmental cost.

3.2 Applications

The applications of superabsorbent materials are varied (5% in food applications). However, hygienic applications are the most common (Figure 1). In this way, 95% of SAPs are used for baby diapers, feminine sanitary products and adult incontinence products [14], although these products pose the greatest problem regarding the generation of primary microplastics and pollution in landfills due to their low biodegradability [49].

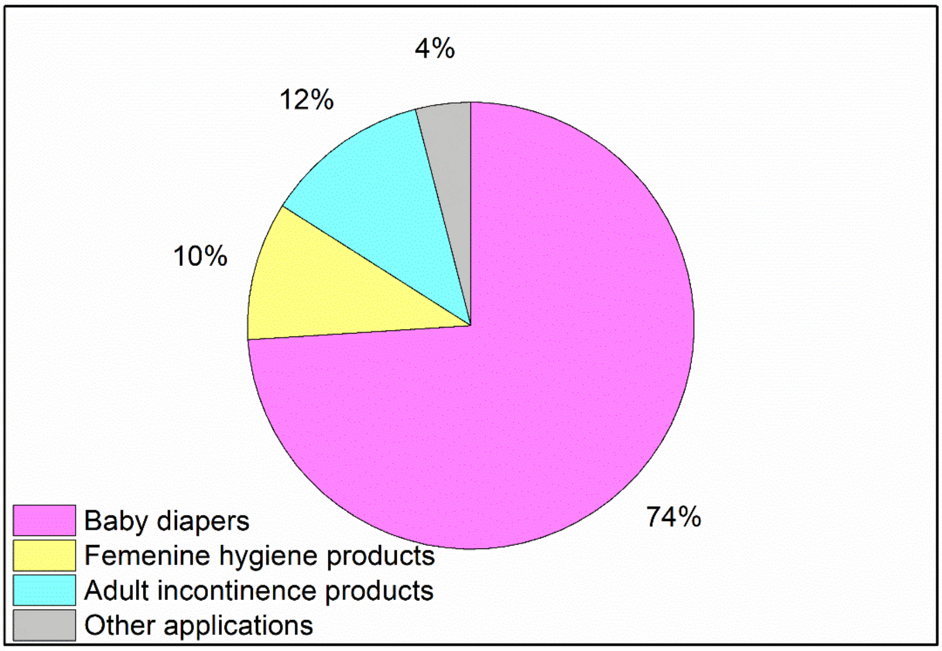

Figure 1: Global applications of superabsorbent materials.

In this way, the most of research about SABs also refer to these hygienic devices, since they try to solve the environmental problems that hygienic SAPs generate. However, their greater biocompatibility and biodegradability imply that they are also being investigated in other areas such as agriculture (e.g., to improve the water cycle efficiency) [50,51], pharmaceuticals (e.g., wound dressings) [52,53], and food packaging (e.g., to maintain moisture and organoleptic properties of meat products) [47,54]. Even so, these applications are still under development and further research is needed before they can be found competitively in the market.

4. CONCLUSIONS & FUTURE PERSPECTIVES

The use of biowastes for the production of biodegradable materials that have a positive impact on the environment can favor the current economy. In this way, they would contribute to the move towards a circular economy philosophy, with a concept of zero waste and, thus, contribute to current policies. In addition, the use of these biowastes could also be a potential support to developing countries whose main economy is based on the primary sector, with large crop losses due to climate change. Thus, Figure 2 shows the growing trend of research on SABs in the last few years.

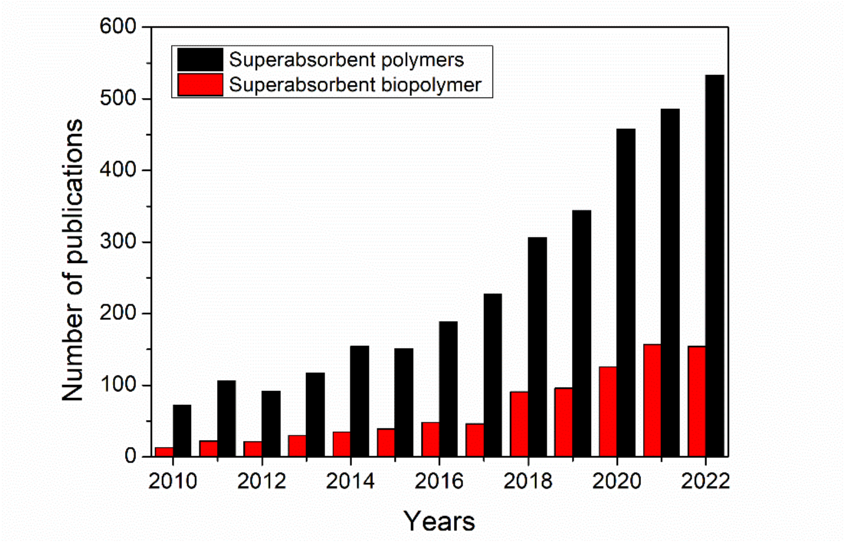

Figure 2: Publications related to superabsorbent materials from polymers and biopolymers in the last years. Data obtained from Science Direct.

Although numerous studies on SABs based on biowastes have been published in recent years, there is still a long way to go before these materials can compete with conventional ones. In this way, it is necessary to improve their absorbent properties without harming their mechanical strength since they are necessary so that the products can be used without breaking or releasing the absorbed water (for example, superabsorbent materials used in trays must support the weight of the meat without releasing absorbed liquid). In addition, this improvement must not harm the eco-friendly nature of these materials. On the other hand, they also need to be economically competitive in order to be accepted in the current capitalist system [14]. In this sense, recent research has suggested that the mixture of different proteins or proteins/polysaccharides can generate synergies between the different biopolymers, improving the qualities of the final materials [55,56]. On the other hand, the inclusion of nanoparticles obtained by green synthesis also seems to be a route with great potential since could extend the benefit of these materials [57,58]. In this way, aluminum nanoparticles have been used to improve the antimicrobial activity of chitosan materials [57] and copper oxide nanoparticles have improved antioxidant activity of starch-based materials [59].

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Table Legend

Table 1: Different biowastes used as raw materials for superabsorbent materials.

Figures Legends

Figure 1. Global applications of superabsorbent materials.

Figure 2. Publications related to superabsorbent materials from polymers and biopolymers in the last years. Data obtained from Science Direct.