Use of essential oils and biodegradable packaging in food: an alternative to reduce environmental impacts and improve food safety

Jean Pereira[1][0000-0003-2107-3383], Nicole Cecchele Lago[2][0000-0003-1523-6713], Camila Kolling[2][0000-0002-7354-6886], Janine Fleith de Medeiros[1][0000-0002-5060-0632] and Jose Luis Duarte Ribeiro[2][0000-0002-5795-4468]

[1] Graduate Program on Business Administration and Graduate Program on Environmental Sciences, Universidade de Passo Fundo (UPF), Brazil
[2] Industrial Engineering Graduate Program, Universidade Federal do Rio Grande do Sul (UFRGS), Brazil

Abstract. Based on a systematic literature review, this study aims to list the main essential oils used in biodegradable films in the context of food packaging. Although some studies have developed and tested specific possibilities regarding more sustainable alternatives for these packaging, there is no systematization regarding the possible materials used in developing packages using essential oils or compounds found in essential oils. We describe the main materials used for film forming with natural polymers. Among these materials, the mixture of organic compounds stands out, which intends to unite the mechanical and formation properties, aiming at film structures applicable to food packaging. Results can contribute to sustainable development in the food industry since incorporating essential oils in biodegradable films is an alternative to reducing environmental impacts. Thus, seeking helping decision-making processes in the food industry, we systematized the results by describing each material's advantages and disadvantages.

Keywords: Green Packaging, Food Safety, Sustainability.

1 Introduction

Packaging is a central concern in the food industry, its functions being associated with food preservation, quality maintenance, and safety [1]. To achieve these goals, plastics based on petrochemical products are still widely used due to low production costs, good mechanical strength, and adequate water and gas barrier properties [2].

However, these plastics are compounds not degraded by microbial action due to the excessive length of their molecular chains [3]. Their degradation is a slow process that may take 100 to 400 years [4]. Estimates drawn from data collected from 1950 until 2015 indicate that approximately 60% of the plastics developed have been disposed of and are accumulating in landfills and the environment, while only 9% of plastics have been recycled [5]. The accumulation of plastic impacts the health of land and aquatic animals [6, 7] and facilitates the spread of contaminating agents [8].

To mitigate the aforementioned problems, technologies with a green approach are sought that involve the management of waste and biodegradable materials. These technologies include biodegradable active packaging [9] with the incorporation of essential oils (EOs). EOs are aromatic compounds with great potential for application in biodegradable active packaging for food, mainly due to their natural origin and their functional properties (antioxidants and antimicrobials) that allow obtaining active materials with the ability to extend shelf life and aggregate value to the product [10]. The advantage of using EOs in active packaging is their bactericidal and fungicidal properties.

In this context, research to find new preservation alternatives has been increasing within the food industry [11], and the use of EOs in packaging is widespread as an alternative to synthetic chemicals [12]. In addition to making food healthier and more visually attractive, social and environmental responsibility attributes have become relevant [8]. For example, the film is an alternative edible and biodegradable [13], which, when incorporated into EOs, enables the production of materials with the ability to extend the shelf life of food products, adding value to these products, through enhanced functionality and sustainability [14]. This is due to the EOs' naturalness and antioxidant and antimicrobial characteristics.

Nonetheless, while most studies concerning oils are focused on film composition and functions (scientific aspects), few studies are dedicated to developing and transferring said technology so that it may be effectively used on a large scale [13]. It means there is no systematization regarding the possible materials that can be used in developing packages using EOs or compounds found in EOs.

To fill this gap, this study aims to list the main essential oils used in biodegradable films, which were scientifically tested, validated, and reported in the literature. For this, we adopted the following research question: *What are the primary materials tested and scientifically validated to produce biodegradable films for applying EOs?* To answer this question, we conducted a systematic literature review, which allows the synthesis of research contributions in determining fields [15]. In this study, as our focus is to map several possibilities of essential oils and not to test any specific type, this is only possible through an in-depth study of the literature. In addition, there are many studies testing different specific materials, but this compilation and organization of materials that have already been tested are still lacking.

The systematization of this knowledge is important for the food industry to make better decisions, prioritizing materials that can effectively reduce the use of chemical additives in the food industry. Therefore, results can contribute to reducing environmental impacts, being an additional path towards sustainability in the food industry. In addition, the identification of EO in the context of green packing is justified, given its great potential for application in biodegradable active food packaging. By understanding which EO can be used in green packaging, manufacturers can select the most appropriate ingredients for their products and minimize the environmental impact of their packaging. Identifying EOs is also important to ensure that green packaging is safe for use. In this way, the information generated in this study can support the industry's and consumers' decision-making.

2 Method

We conducted a systematic literature review, following the steps and procedures comprising: (i) setting the goal; (ii) database selection; (iii) keywords definition; (iv) article selection; (v) data extraction and analysis [15, 16]. Figure 1 represents the synthesized flow of the systematic review.

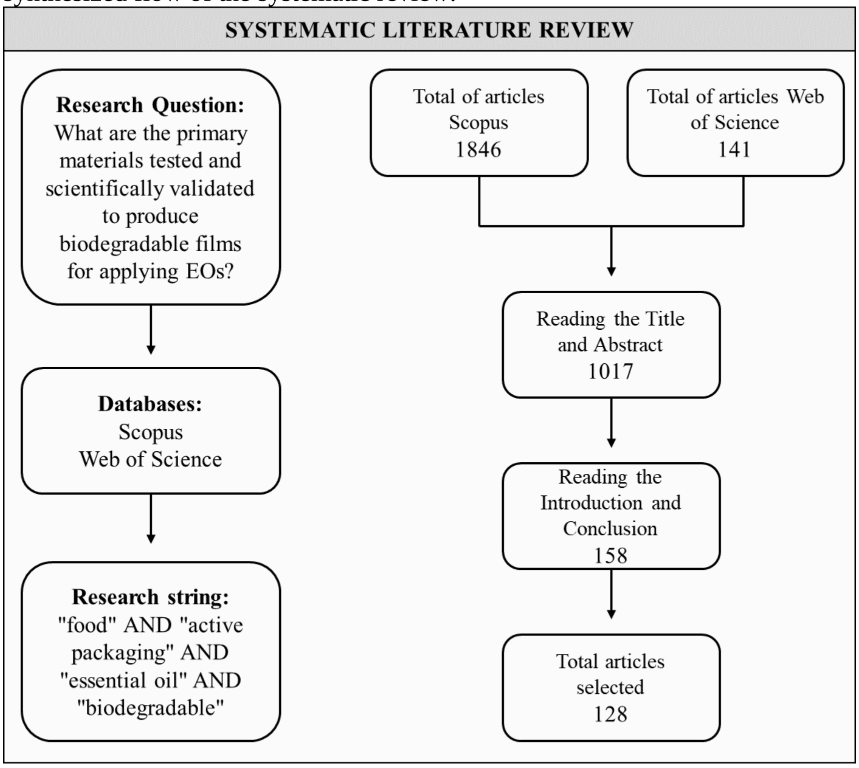

Fig. 1. Article selection flowchart.

To meet the (i) goal set, we defined the research question. Afterward, we (ii) selected the Scopus and Web of Science databases to search for articles. We justify the choice of these databases due to the extensive number of qualified journals they have. The data search was carried out in March 2023.

A (iii) combination of keywords was defined through the string: ("food" AND "active packaging" AND "essential oil" AND "biodegradable"). These words had to be found in the articles' titles, keywords, and abstracts. In the (iv) article selection step, we include research articles published only between 2017 and 2023, especially because this is a recent research topic, and the largest volume of publications is concentrated from 2017 onwards. We also only included research articles in English and published in journals. Literature reviews were not included in our sample. We read titles and abstracts of retrieved papers and selected papers that explicitly addressed the application of non-biodegradable films or packaging in the food sector.

Afterward, we excluded duplicated articles retrieved in both databases and read the introduction and conclusions section of selected studies to certify that the article dealt with a tested and validated material to produce biodegradable films for applying EOs. Based on this, the selected articles were read in full and summarized during the (v) data extraction and analysis. In this step, we employed content analysis since it enables the systematic compilation of results based on replicable and valid inferences [17]. More precisely, we employed deductive content analysis, as the data were initially coded according to existing polymer categories in the literature [17]. This categorization allowed us to obtain a more comprehensive view of the selected articles as we organized a spreadsheet summarizing the content of the articles classified according to the different polymers regarding the applicability, benefits, and disadvantages of each one. We also gathered additional information that could be interesting to organize the results better (e.g., the formation of the film matrix and the organic compounds, EOs, and active compounds used in the study).

Three researchers participated in the steps of article selection and data extraction and analysis, increasing the study's validity. Table 1 presents a description of the profile of the selected evaluators to ensure that the results obtained are reliable and the risks of bias are minimized. The standardized search protocol also increases the study's validity since the search string is directly linked to the research question. Likewise, the use of a standardized data analysis protocol contributes to increasing validity. Regarding reliability, given that it represents the extent to which the operations of a study can be repeated, generating the same results [18] we provide a detailed description of how the review was conducted, which allows replication by other researchers.

Table 1. Profile of the evaluators.

	Profile
Evaluator 1	Food Engineer. He has two years of experience developing biodegradable packaging with pH indicators from agro-industrial waste.
Evaluator 2	Advertising professional and Ph.D. in Production Engineering. She is currently a university professor and works directly in developing research aimed at green product innovation, pro-environmental behavior, and responsible communication.
Evaluator 3	Industrial Engineer and Ph.D. candidate in Industrial Engineering. She develops research in innovation, environmentally sustainable consumer behavior, and pro-environmental disposal behavior.

3 Results

The main biodegradable compounds for incorporating EO are shown in Table 2. The most used natural polymers for forming biodegradable filmogenic matrices, aiming at applying and incorporating EO, are (a) polysaccharides and (b) proteins.

The (a) polysaccharides most studied in recent years were chitosan, starches, and derivatives. Among them, there is a greater emphasis on chitosan, which is obtained through a chitin deacetylation process. Chitosan is present in the exoskeleton of marine animals and fungi. It is a viable alternative for sustainable applications, as it can be obtained from by-products and residues from fishing activities.

The (b) proteins that received the most attention in the studies carried out were gelatin and whey protein. Regarding gelatin, studies have shown that there is an incidence of using resources obtained from by-products and residues from marine animals in a similar fashion to chitin. Whey protein, in turn, has been considered an organic compound with great added value to produce dairy products and food supplements. It has recently been drawing attention to its use in producing biodegradable films.

Table 2. Natural polymers for food packaging.

Group	Polymer	Authors
Polysaccharides	Starches and derivatives	[19–35]
	Chitosan	[36–53]
	Pectin	[54, 55]
Proteins	Caseinates	[56]
	Gelatin	[57–63]
	Soy protein	[64]
	Whey protein	[65–69]
	Zein	[70]
Blends of polymers	Polysaccharides + Proteins	[1, 2, 71–98]
	Polysaccharides + Polysaccharides	[76, 99–110]
	Polysaccharides and another compound	[14, 111–131]
	Protein and another compound	[132–137]

In recent years, particular emphasis has been given to mixing organic compounds to form biodegradable films. Research in this area proposes to verify the interaction of the mixture of organic compounds and discuss the feasibility of applying and improving the mechanical structures of the formed films. For example, nanoclay compounds can provide more resistant films, improving tensile strength [14, 113, 117, 121]. The use of proteins with carbohydrates has also been extensively studied, especially the use of chitosan with another protein compound [71–75, 78, 80, 86, 88, 89, 93, 94, 103, 118, 119, 135, 136]. Using chitosan in conjunction with protein compounds tends to unite the antimicrobial capacity of chitosan with a good structure for forming filmogenic matrices that proteins provide.

4 Systematization of the results

Based on the systematic review results, we identified strengths and weaknesses related to the types of bases used for film forming. In this sense, we summarized the advantages and disadvantages of polymers for EO application (see Table 3). This systematization may be helpful to assist in the decision-making process in the food industry.

Table 3. Advantages and disadvantages of polymers.

Polymer	Advantages	Disadvantages
Polysaccharides and Proteins (30 researches)	Homogeneous films with good mechanical resistance, mainly due to chitosan films with gelatin. Also, EOs provide better water vapor barrier properties, and the thickness tends not to interfere negatively.	The presence of protein in the films resulted in a deterioration of the microstructure due to the increase in pores and a worsening of the tensile strength with the plasticizing effect of the EO.
Polysaccharides and another compound (22 researches)	Starch films incorporated with montmorillonite demonstrated synergistic effects with the effects of EO. In a study, the EO was protected against evaporation and volatilization, prolonging and optimizing the bactericidal effect. In another study, the incorporation of titanium dioxide nanoparticles provided an effect of filling voids and porosity that sago starch films form.	The interaction of EOs with polysaccharides and other compounds tends to increase the plastification process, which may be a non-beneficial factor depending on the application. This plasticizing effect is due to phase separation. The incorporation of cinnamon EO into sago starch matrices generates negative effects on the mechanical and barrier properties.
Chitosan (18 researches)	Good homogeneity, along with naturally having an antimicrobial effect. When combined with EOs, antimicrobial capacity was	Depending on the application, film flexibility may be an issue. In addition, there is less tensile strength and more color deterioration (darkening) with

	increased, in addition to improved mechanical properties and less solubility, bloating, and swelling. Furthermore, the addition of clay compounds improved tensile strength and barrier capacities.	the application of some EOs, and some films became brittle.
Starches and derivatives (17 researches)	Homogeneity and good interactions with EOs, conveying less permeability to water vapor, greater tensile strength, less moisture content, and greater elongation.	Low resistance and diminished mechanical properties. Increased opacity depends on the incorporation of oils, which decreases interaction due to a barrier preventing the passage of light. Customers have a poorer perception of these products.
Polysaccharides and Polysaccharides (13 researches)	The inclusion of Salvia reduced the moisture content and permeability of potato starch and sour gum films. In the same sense, the addition of thyme in chitosan films and pomegranate extract decreased the solubility of biodegradable films. The cassava starch combo with lemongrass and pectin emulsions provided good mechanical properties to the biodegradable films.	The incorporation of EO provided a yellow color to the films. In contrast, there was a decrease in tensile strength for all films studied (chitosan, xanthan gum, pullulan, gum tragacanth, and gum arabic).
Gelatin (7 researches)	Low thickness change capacity with the addition of other compounds (EOs, clay, and other compounds). In addition, cinnamon EO conferred less moisture to films, while bergamot oil conferred greater tensile strength.	Films combined with EOs showed a worsening in tensile strength compared to pure films.
Protein and another compound (6 researches)	The permeability of sodium caseinate films decreased with the application of zinc nanoparticles. This is due to the strong molecular interactions of caseinate with zinc nanoparticles, providing more compact and dense films with greater barrier properties.	The addition of zinc or montmorillonite nanoparticles harms the action of the EO due to greater conformity of the structure of the biodegradable films.

Whey protein (5 researches)	Homogeneous, compact, and smooth structures. The films have a nice color and are translucent. The interaction with EOs was deemed satisfactory, with films presenting improved mechanical properties in terms of tensile strength, tension, and rigidity. EOs increased the elongation of the films.	In some cases, EOs caused cracks and holes in the homogeneous structure of whey protein films. Also, it causes color deterioration due to darkening and decreased tensile strength in cases with a plasticizing effect.
Pectin (2 research)	Less permeability to water vapor. Also, a medium elastic modulus is verified without the use EOs. Clay compounds tend to act as reinforcers, generating greater tensile and breaking strength. The oily phase of the oils causes an increase in film elongation, improving one of the basic mechanical foundations.	Unlike other materials used to produce films, pectin, in combination with EO, results in decreased elasticity, making films opaque.
Caseinates (1 research)	Greater thermal stability and the EOs slightly increased the tensile elongation at break.	Fragile films, without rigidity and brittle. Less tensile strength and elastic modulus.
Soy protein (1 research)	Flexible (which may be a strong point depending on the application) and translucent films. Suitable thickness and hydrophobicity levels when combined with EOs.	EOs worsened the films, causing a darkening and decreased tensile strength of films with soy protein compared to pure films.
Zein (1 research)	Pure zein films have low solubility. Still, the thermal stability was higher with plasma treatment due to the controlled kinetic release of the treatment.	Less rigidity due to the plasticizing effect.

5 Conclusions

There is an increasing demand for technologies devised to make up and create biodegradable film matrices, especially the ones originating from natural polymers. Thus, we seek to develop a guide to emerging technologies involving EOs and biodegradable packaging for food technology researchers.

The food industry can benefit significantly from using EOs or their constituent because their application can reduce environmental impacts and improve food safety. In this sense, the use of food residues for the formation of biodegradable packaging of natural origin can be both for the use of carbohydrates and proteins, each having its particularity in terms of filmogenic aspects (for example, some materials make packaging more resistant than to others). The incorporation of EO is a way to reduce the use of chemical additives typically used by the food industry to control microorganisms and increase the shelf life of some products.

This study summarized the advantages and disadvantages of polymers for EO application, providing helpful information to the decision-making process in the food industry. The research also advances the discussions on sustainable alternatives for food packaging that can contribute to the sustainability and circularity of the food industry. Additionally, we provide insights for creating public policies focused on using more sustainable and safe materials in food packaging.

Theoretically, the study advances the theory on EO in green packaging research, given that the existing contributions so far were empirical and focused on specific types of materials. Our research can help in the development and research of new packaging materials that are more environmentally friendly and safe. In addition, this research contributes to the theory of sustainable business and management. The information provided in this study can contribute not only to the reduction of environmental impacts, but also cost reduction and economic sustainability of companies.

The results described herein help to replicate studies aimed at confirming on a considerable scale the results obtained in lab experiments. We recommend that the subsequent research involves economic feasibility studies focused on the compounds most likely to be efficient and effective, as described in this paper. We highlight that the string used to search for articles and the publication period restriction may be a weakness of the study. Therefore, we suggest that future studies replicate our search string, adding terms such as “primary materials” and only “packaging” instead of “active packaging”, for example. Finally, public policies can be defined to spread knowledge about the benefits arising from the use of EOs and biodegradable food packaging.

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The complete list of references, including the 128 articles selected in the systematic review, can be found at the link: http://www.producao.ufrgs.br/arquivos/References_EOsBiodegradablePackFood.pdf