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Review Article

Impact of Edible Films as an Alternative for Food Packaging

Impacto de las películas comestibles como alternativa de envase de alimentos

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ABSTRACT

This study evaluates the impact of edible films as a sustainable and biodegradable alternative for food packaging in response to the growing issue of plastic pollution. The objective is to analyze the effectiveness of these films in terms of sustainability, multifunctionality, and food waste reduction. A systematic literature review (SLR) was conducted using scientific databases, selecting relevant studies published between 2019 and 2024 based on specific criteria and following the PICOC, BIBLIOMETRIX, and PRISMA methodologies. The results reveal that 64.29% of the studies consider edible films to be beneficial, emphasizing not only their biodegradability but also their ability to protect food, extend shelf life, and reduce environmental contamination. In addition, their antimicrobial and antioxidant functionalities are highlighted, with materials such as gelatin, chitosan, and other natural polymers being commonly used. In conclusion, edible films represent a promising solution for reducing plastic pollution and improving food preservation, positioning themselves as an eco-friendly alternative within the packaging industry. However, further research is needed to optimize their production and efficacy across various applications.

Keywords: Biodegradable, edible films, environmental pollution, sustainable alternative.

RESUMEN

Este estudio evalúa el impacto de las películas comestibles como una alternativa sostenible y biodegradable para el envasado de alimentos, en respuesta a la creciente contaminación por plásticos. El objetivo es analizar la eficacia de estas películas en sostenibilidad,

multifuncionalidad y reducción del desperdicio alimentario. Se llevó a cabo una revisión sistemática de la literatura (RSL) en bases de datos científicas, seleccionando estudios relevantes publicados entre 2019 y 2024 mediante criterios específicos y las metodologías PICOC, BIBLIOMETRIX y PRISMA. Los resultados revelan que el 64,29 de los estudios considera que las películas comestibles son beneficiosas, destacando no solo por ser biodegradables, sino también por su capacidad para proteger los alimentos, prolongar su vida útil y reducir la contaminación ambiental. Además, se resalta su funcionalidad antimicrobiana y antioxidante, utilizando materiales como gelatina, quitosano y otros polímeros naturales. En conclusión, las películas comestibles son una solución prometedora para reducir la contaminación plástica y mejorar la conservación de alimentos, presentándose como una alternativa ecológica en la industria de envases. Sin embargo, es necesaria más investigación para optimizar su producción y eficacia en diversas aplicaciones.

Palabras clave: Biodegradable, películas comestibles, contaminación ambiental, alternativa sostenible.

INTRODUCTION

In recent years, restrictions on the use of plastics have increased due to the growing environmental pollution problem (Suresh, 2021). Consequently, the packaging industry is seeking to achieve sustainable production, and one of the most promising alternatives is the use ofedible films as substitutes for plastics, given their biodegradable and multifunctional nature (Athanasopoulou *et al*., 2024).

The importance of these films lies in the fact that they are produced from natural polymers—such as proteins and polysaccharides—and even from certain food residues like fruit peels, thereby helping to reduce global food waste (Schmoldt *et al*., 2024). It is estimated that each year, 121 kilograms of food are lost per person worldwide, with the majority of this waste occurring at the household level (United Nations, 2022).

Global plastic production reaches 400 million tons annually, of which 162 million tons are generated by the packaging industry. This poses a major environmental challenge, as plastic is a non-biodegradable material that takes centuries to decompose, resulting in solid, non-destructible waste and toxic by-products, while also contributing to food waste (Merino *et al*., 2024).

In Peru alone, three million plastic bags are used each year. However, a Supreme Decree has been enacted to promote the reduction and replacement of plastics with reusable, biodegradable materials whose degradation does not produce microplastic contamination (MINAM, 2019). For this reason, technology is focusing on the development of antibacterial and biocompatible packaging materials that can extend food shelf life and reduce environmental impact. Research is also exploring new biodegradable ingredients for the production of such materials (Solano *et al*., 2018).

Edible packaging films act as a protective barrier between food and the packaging material, preventing direct contact, reducing contamination, and improving food safety (Tang *et al*., 2024). This technology is gaining popularity as a sustainable alternative to traditional packaging, thanks to its ability to reduce plastic waste and enhance

food safety. In recent years, the field has advanced rapidly, with new formulations, manufacturing methods, and applications being developed—many of which have not yet been fully documented in prior reviews.

Therefore, the objective of this review is to determine the impact of edible films as an alternative food packaging solution within the food industry.

MATERIALS AND METHODS

A total of 124 articles relevant to the topic were identified in the Scopus database. The PICOC model was then applied to break down the research topic into key terms to enable a more comprehensive search within Scopus.

PICOC Methodology

A Systematic Literature Review (SLR) differs from traditional narrative reviews due to its replicable, scientific, and transparent approach. Its goal is to collect all relevant documents and publications that meet predefined inclusion criteria to address a specific research question. When conducted rigorously and with minimal error, an SLR can provide reliable results and conclusions that guide decision-makers and scientific professionals in their work (Mengist *et al*., 2020).

General Research Question

Q1: What is the impact of edible films made from natural sources as a sustainable alternative to replace plastic food packaging?

Specific Research Questions

SQ1: What are edible films?

SQ2: What natural sources are used in the production of edible films?

SQ3: Why should plastic packaging be replaced?

SQ4: Why are edible films considered sustainable alternatives for food packaging

Both Spanish and English keywords were used based on the research questions. To refine the search process, keywords were combined with Boolean operators, and the IATE database (Interactive Terminology for Europe) was consulted to standardize terminology and organize the search effectively (Abdul *et al*., 2024).

Boolean operators are an essential tool in scientific literature searches, as they allow researchers to refine, broaden, or limit results using the terms “AND,” “OR,” and “NOT.” This technique helps exclude irrelevant studies and improves the precision of search results (Abdul *et al*., 2024). Articles related to the research topic were selected according to each criterion defined within the PICOC matrix.

Formulation / Selection of Search Equations and Search Engines

The Scopus database was used, as it is considered the largest existing multidisciplinary database. The keywords were combined with Boolean operators (AND, NOT, and OR) and enclosed in quotation marks to conduct a more systematic, focused, and versatile search.

Bibliometrix Analysis

Bibliometrix (R language) is recognized as a highly effective tool for analyzing large volumes of data, allowing researchers to organize conceptual and intellectual frameworks through the examination of quantitative data and their visual representations (Campina *et al*., 2024).

Table 1.
Search strings

Words/Search strings	Number of articles
("Sustainable" or "Packaging" or "Food" or "Environmental Problems" or "Plastic" or "edible film" or" Non-biodegradable" or "Food Industry") AND ("Edible films" OR "Food packaging" OR "Conservation" OR "Environmental viability" OR "Acceptance") AND ("Natural sources" OR "biopolymers" OR "edible films" OR "biodegradable packaging") AND ("Substitution" OR "plastic containers" OR "edible films" "shelf life" OR "waste" OR "foods") AND ("Biodegradable packaging" OR "food industry " OR "food innovation" OR "sustainable production")	128

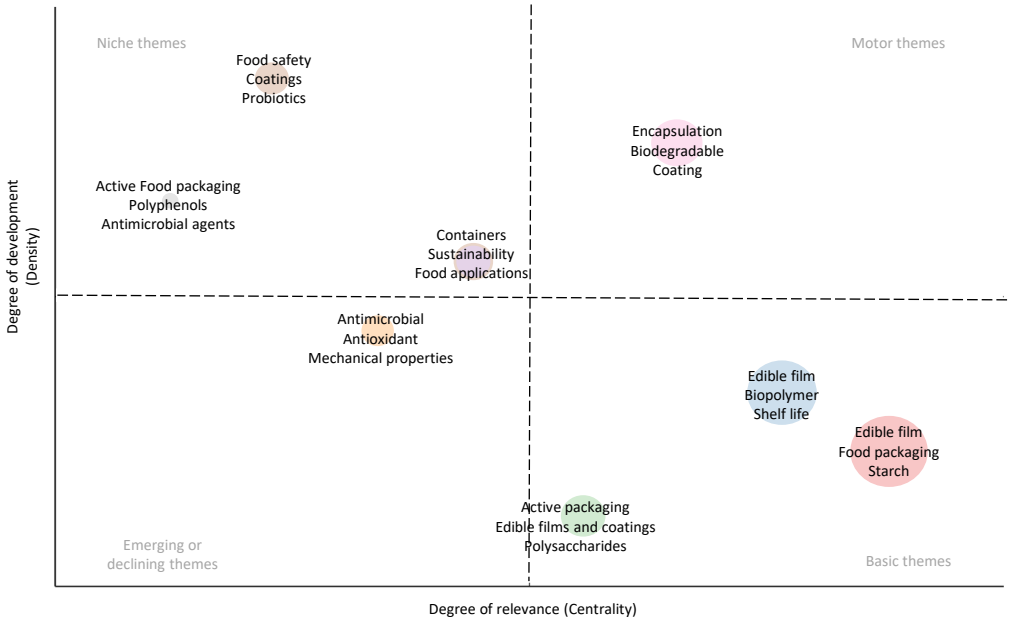

Figure 1. Thematic Map of Keywords

Results of the Bibliometrix Analysis in R Studio

The bibliometric analysis performed in R Studio revealed a steady growth in the rate of published articles, which can be expressed as 14.47%. The analysis also allowed for visualization of the relationship between keywords and the years of publication of each study, spanning from 1996 to 2024. The size of each node represents the frequency with which a given keyword appears across the analyzed documents.

Inclusion and Exclusion Criteria

Inclusion and exclusion criteria are established by authors during the development of a Systematic Literature Review (SLR) to minimize potential bias. These criteria (IC and EC) must be defined a priori and be highly specific—overly broad criteria can make it difficult to draw clear conclusions from the results. Article selection is based on factors such as language, source impact, open access availability, and year of publication (Khan *et al*., 2022).

For this study, the primary inclusion criterion was the selection of scientific articles published within the last five years (2019–2024) to ensure the use of up-to-date information. Table 2 presents the six inclusion criteria and one exclusion criterion applied to this SLR.

After conducting an exhaustive search in the SCOPUS database and applying the PRISMA flow diagram along with the inclusion and exclusion criteria shown in Table 3, an initial total of 4690 records was obtained. Since the study used only SCOPUS, there were no duplicate records. After screening, 469 records remained. Applying the PICOC methodology together with the inclusion (IC1, IC2, IC3, IC4, IC5, IC6) and exclusion (EC1) criteria, a total of 42 articles were finally selected for the Systematic Literature Review (SLR), as shown in Figure 2.

Table 2.
Scientific Article Search Criteria (PRISMA)

Type	Inclusion criteria	Type	Exclusion criteria
CI1	Articles published within the last five years (2019–2024)	CE1	Articles older than five years
CI2	Subject areas: Chemistry, Biological and Agricultural Sciences, Environmental Sciences, and Engineering		
CI3	Document type: Research article		
CI4	Keywords: edible films, food packaging, chitosan, biopolymers, starch, edible coatings, packaging, shelf life.		
CI5	Language: English		
CI6	Open Access		

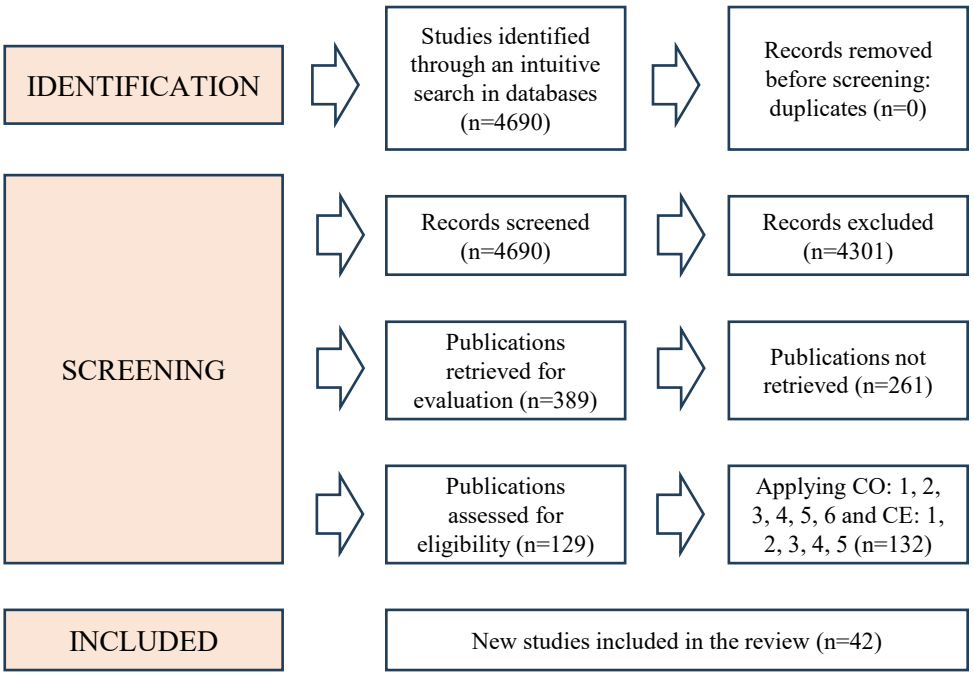

Figure 2. PRISMA Flow Diagram

RESULTS AND DISCUSSION

1. Results by Year of Publication

In 2021, twelve studies on the topic were published, representing 28.6% of the total publications, a higher proportion compared to previous and subsequent years. This suggests that research on edible films as sustainable food packaging alternatives is relatively recent, with increasing interest and development in subsequent years.

2. Number of Publications by Country

According to the findings, India accounted for the largest number of publications, with five studies (7.14%), followed by Brazil with four (5.71%). Next were Saudi Arabia, Malaysia, Iran, Indonesia, China, and the United Kingdom, each contributing three publications (12.87%). Countries such as Turkey, Spain, Portugal, Oman, Mexico, and Argentina had two studies each (21.06%), while other nations contributed one publication each (26.25%).

3. Results from the PICOC Research Questions

1: What is the impact of edible films made from natural sources as a sustainable alternative to replace plastic food packaging?

Based on the results, 27 studies (64.29%) reported that edible films have a positive impact as an alternative to plastic packaging. These studies emphasize the biodegradability, protective properties, and environmental benefits of edible films. Meanwhile, 15 studies (25.71%) did not explicitly define the impact as positive or negative, but none reported adverse effects.

Edible films and sustainable packaging systems aim to reduce single-use plastics and promote biodegradable alternatives that enhance the preservation of both perishable and dry foods. These approaches integrate biopolymeric and synthetic materials for functional design, collectively

contributing to plastic pollution reduction and the promotion of sustainable practices in the packaging industry.

According to de Souza *et al*. (2024), edible films formulated with anthocyanins and Deep Eutectic Solvents (DES) provide not only ecological benefits but also stable and functional physical properties, making them viable for industrial use. Similarly, Aziza *et al*. (2023) highlights that edible films from natural sources improve food preservation while mitigating the environmental impact of single-use plastics. Furthermore, Pavlatkova *et al*. (2023) reports that edible films based on zein and chitosan, enhanced with natural antimicrobial agents such as essential oils, serve as a sustainable and effective alternative to plastic packaging by improving barrier properties and reducing the need for synthetic additives. These solutions not only offer barrier and preservation properties but also contribute to reducing the use of chemical additives, promoting a more eco-friendly and safer option for food packaging. These authors emphasize that edible films enhance food preservation by providing improved barrier properties and stability.

Terzioglu *et al*. (2024) adds that edible films and other innovative solutions complement each other in addressing plastic pollution and achieving a more sustainable packaging industry that is less dependent on conventional plastics. In line with this, Gamboni *et al*. (2023) asserts that edible films made from natural polymers share the same goal as other sustainable packaging systems: to reduce plastic waste and enhance environmental performance in food industries such as instant coffee packaging. Gamboni *et al*. (2023), Aziza *et al*. (2023), and Pavlatkova *et al*. (2023) agree on the use of natural sources for the development of edible films, emphasizing their focus on eco-friendly solutions. Terzioglu *et al*. (2024) highlight that edible films and other approaches are complementary in addressing plastic pollution, while other authors, such as De Souza *et al*. (2024) and Pavlatkova *et al*. (2023), focus more on the feasibility of edible films as a unique and effective solution.

Results for the Question SQ1

SQ1: What are edible films?

The analysis showed that most studies define edible films as coatings, with 11 articles (42.31%) using this term. Meanwhile, 8 studies (30.77%) refer to them as edible materials, and 7 (26.92%) as packaging materials. Although no single definition exceeds 50%, the prevailing concept describes edible films primarily as coating systems

According to Phengnoi *et al*. (2023), edible films are an innovative technology designed to extend food shelf life by improving water vapor permeability and reducing weight loss in products such as guava. Similarly, Atta *et al*. (2021) report that cellulose-based and yeast-derived edible films exhibit high water solubility and antimicrobial activity, extending the shelf life and quality of fruits like oranges and tomatoes. Phengnoi *et al*. (2023) and Atta *et al*. (2021) agree that edible films are used to extend the shelf life of foods. Phengnoi *et al*. (2023) focus on guava, improving water vapor permeability and reducing weight loss, while Atta *et al*. (2021) highlight their application in fruits such as oranges and tomatoes, emphasizing high water solubility and antimicrobial activity.

Otálora *et al*. (2022) describes edible films made from cassava starch and vegetable microparticles, which improve

tensile strength and can even detect food spoilage.

Pavlatkova *et al*. (2023), on the other hand, focuses on zein and chitosan-based films incorporating essential oils for added antimicrobial activity. Both studies highlight the importance of natural materials and their enhanced functionality. Gamboni *et al*. (2023) adds that edible films are used as primary packaging for dry foods like instant coffee, valued for their tensile resistance and heat-sealing properties.

Gamboni *et al*. (2023) and Otálora *et al*. (2022) address the specific applications and mechanical properties of edible films. Gamboni *et al*. (2023) mention their use as primary packaging for dry foods, such as instant coffee, highlighting their tensile strength and heat-sealing resistance. Otálora *et al*. (2022) also discuss mechanical aspects such as breaking tension and contact angle.

Suresh *et al*. (2021) further emphasizes the multifunctional nature of edible films, noting their biodegradability, antimicrobial potential, and biocompatibility, positioning them as a realistic alternative to plastics. Similarly, Al-Harrasi *et al*. (2022) highlights edible films made from chitosan, porphyran, and ginger essential oil, which enhance barrier, thermal, optical, and mechanical properties while providing antioxidant effects.

Suresh *et al*. (2021) and Al-Harrasi *et al*. (2022) highlight the multifunctional properties of edible films, such as biodegradability and antimicrobial activity. Suresh e*et al*. (2021) focus on the ability of these films to replace plastic materials, while Al-Harrasi *et al*. (2022) emphasize improvements in barrier, thermal, optical, and mechanical properties, as well as their antioxidant effects.

Results for the Question SQ2

SQ2: What are the natural sources used in the production of edible films?

According to the results obtained from various natural sources used in the production of edible films, as shown in Figure 3, the most common sources are plant-based materials, representing 52.63%, followed by gelatin and chitosan at 31.58%, and finally animal-based sources at 15.79%.

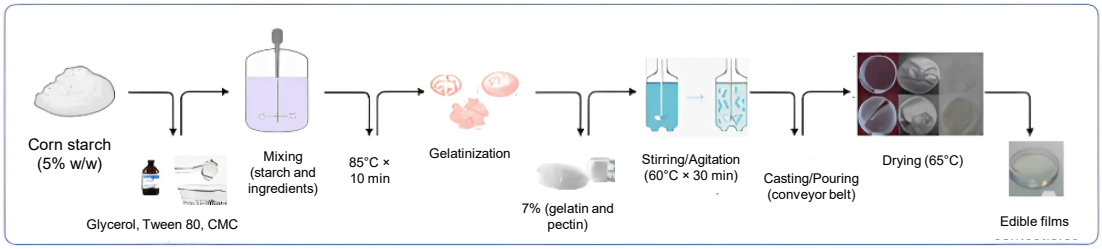

Figure 3. Production process for edible films

Chen *et al*. (2024) investigated the use of mango peels and tea polyphenols to create antibacterial films. These films exhibited greater density and significant improvements in their barrier properties against water vapor, oxygen, and carbon dioxide.

The combination of mango peels and tea polyphenols helped maintain the color and texture of chicken breast meat, inhibiting microbial growth and extending the product's shelf life. Meanwhile, Han *et al*. (2023) developed a composite edible

film using zein, shellac, and curcumin. The addition of curcumin notably enhanced the film's water vapor barrier, water solubility, and antioxidant properties. Moreover, these films demonstrated pH responsiveness and inhibitory effects against E. coli, providing a new strategy for developing functional food packaging.

Mondal *et al*. (2022) explored the use of defatted green algae biomass and chitosan to produce edible films. They utilized an ethanolic extract of raw algae, achieving improvements in tensile strength, antioxidant activity, and water vapor permeability. This eco-friendly approach offered a sustainable solution for extending the shelf life of fresh products such as green chili peppers. Similarly, Kaur *et al*. (2024) investigated the combination of aloe vera gel and chitosan to form edible films. Their formulations improved rheological and antioxidant properties, as well as water solubility and water vapor permeability. When applied to fresh figs, these films significantly reduced microbial growth during cold storage, demonstrating a sustainable solution for fresh fruit preservation.

In another study, Bahar *et al*. (2023) employed gelatin, zinc oxide nanoparticles, and chitosan nanofibers to enhance the mechanical and barrier properties of edible films. The combination of these materials provided antioxidant and antibacterial capabilities, showing great potential as a functional material for food packaging. Likewise, Tien *et al*. (2021) discussed the use of chitosan and nanoparticles to form nanofibers with excellent antioxidant and antimicrobial properties. Chitosan, often blended with other materials to improve processability, stood out for its intrinsic beneficial properties and its ability to form effective edible films for a variety of food products.

Azizah *et al*. (2023) evaluated a combination of fish gelatin, pectin, and lemongrass essential oil to develop edible films. The resulting films showed improvements in physicochemical properties and antibacterial activity, proving effective in preserving the quality of chicken breast meat during storage. Similarly, Lima *et al*. (2021) used galactomannan from Caesalpinia pulcherrima and Cymbopogon citratus essential oil to coat cheeses. This coating enhanced the microbiological and physicochemical stability of the cheeses during storage, demonstrating a viable alternative for the food industry. Finally, Nigrum *et al*. (2021) combined fish skin gelatin with roselle powder, cinnamon powder, and cinnamon essential oil to develop edible films. These films showed improved physicochemical properties and proved effective as active packaging for bread, standing out for their antioxidant and antibacterial capacities

All the studies agree on the use of natural and biodegradable materials. Chen *et al*. (2024) and Azizah *et al*. (2023) highlight the use of plant-based residues (such as mango peels and pectin), while Mondal *et al*. (2022), Tien *et al*. (2021), and Bahar *et al*. (2023) focus on biopolymers like chitosan. Ningrum *et al*. (2021) and Lima *et al*. (2021) mention biopolymers derived from both animal and plant sources.

Regarding the antioxidant properties of the films, Chen *et al*. (2024) and Han *et al*. (2023) report significant improvements in density and water vapor barrier performance. Mondal *et al*. (2022) and Kaur *et al*. (2024) observe enhancements in mechanical properties and solubility with the addition of bioactive compounds.

The practical applications of these films vary widely — from the preservation

of chicken breast (Chen *et al*., 2024; Azizah *et al*., 2023) and green chili peppers (Mondal *et al*., 2022), to fresh figs (Kaur *et al*., 2024) and cheese (Lima *et al*., 2021). Each author emphasizes how their specific edible film formulations can effectively extend shelf life and maintain the quality of food products.

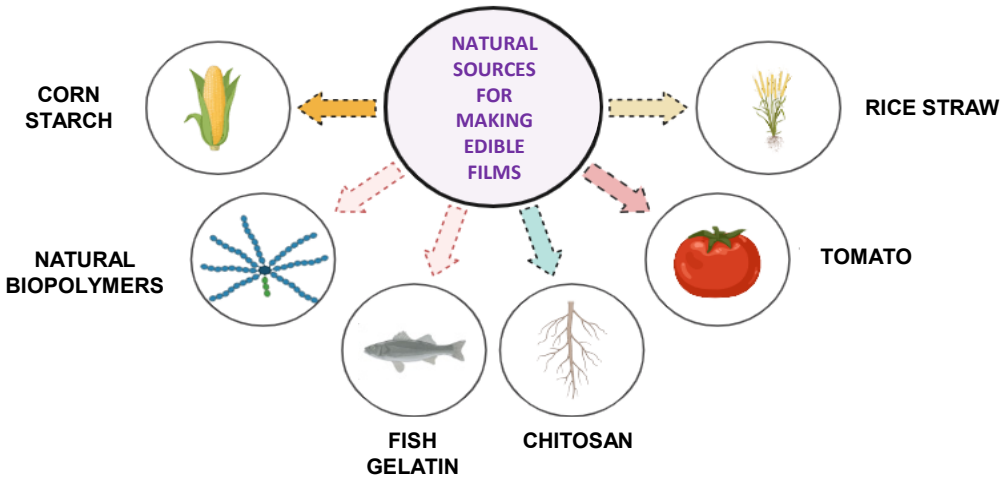

Figure 4. Natural sources for the production of edible films

Results for the Question SQ3

SQ3: Why should plastic packaging be replaced?

Plastic packaging, as is well known, is designed for single use, and in recent years, its use has been increasingly challenged due to the urgent need to reduce or even eliminate it because of its negative impact on the environment. Furthermore, it can also affect human health, as it takes an extremely long time to decompose (Terzioglu *et al*., 2024).

According to the results obtained in this research, there are two main reasons why plastics should be replaced. Fifteen studies (83.3%) indicate that plastics are non-biodegradable and highly polluting, while three studies (16.7%) mention that plastic use contributes to food waste.

Plastic packaging, as is well known, is designed for single use, and in recent years, its use has been increasingly challenged due to the urgent need to reduce or even eliminate it because of its negative impact on the environment. Furthermore, it can also affect human health, as it takes an extremely long time to decompose (Terzioglu *et al*., 2024).

According to the results obtained in this research, there are two main reasons why plastics should be replaced. Fifteen studies (83.3%) indicate that plastics are non-biodegradable and highly polluting, while three studies (16.7%) mention that plastic use contributes to food waste.

Bahar *et al*. (2023) report that environmental pollution has significantly increased in recent years as a result of plastic bag use, which underscores the need to replace this packaging material. Adeyeye *et al*. (2023) agree, stating that the excessive use of plastic packaging materials over the past decades has become a major environmental concern, prompting the call for their substitution and elimination.

Suresh *et al*. (2021) also point out that the majority of conventional plastic packaging materials have caused serious environmental and sustainability issues, creating a need for biodegradable alternatives. Kuprina *et al*. (2020) note that while plastic is accessible and convenient, it is highly detrimental to the environment, as it does not naturally decompose in the short term, accumulating in massive quantities and causing long-term damage to both the planet and human health. Egolf *et al*. (2019) concur that the continued use of plastic packaging is unsustainable, emphasizing the search for eco-friendly alternatives that could transform the food system and make the packaging industry more efficient.Based on the reviewed studies, it can be concluded that conventional plastic packaging must be replaced by biodegradable and sustainable alternatives, since plastic is harmful to both the environment and food quality, and current technologies aim to eliminate its use for a healthier and more sustainable food industry.

Results for Question SQ4

SQ4: Why are edible films sustainable alternatives for food packaging?

According to the results, 35 articles (43.75%) state that plastic packaging should be replaced with edible films because they are biodegradable and sustainable alternatives; 34 articles (42.5%) emphasize their multifunctional properties, and 11 articles (13.75%) highlight their ability to reduce food waste.

Kampeerapappun *et al*. (2024) note that the production of edible film packaging uses biodegradable agricultural residues, integrating eco-friendly raw materials. Bahar *et al*. (2024) identify gelatin as one of the most common biodegradable materials used for edible film production, ensuring sustainability. Likewise, Adeyeye *et al*. (2023) emphasize starch as another environmentally friendly biodegradable alternative that naturally decomposes without causing harm.

Suresh *et al*. (2021) highlight that edible film packaging is biodegradable and sustainable because it is made from natural polymers designed to minimize environmental impact. Atta *et al*. (2021) mention that edible films are potentially sustainable due to their bioactive components, which give them multifunctional roles such as protection and antimicrobial activity. Tien *et al*. (2021) identify chitosan as another sustainable and multifunctional material suitable for biodegradable packaging. Egolf *et al*. (2019) add that food technology increasingly seeks to develop biodegradable and sustainable packaging materials from natural sources, with edible films being among the most promising.

Across all the studies analyzed, edible films developed for packaging purposes are consistently described as biodegradable and sustainable, designed explicitly to replace plastic and address the environmental challenges of recent decades.

The results further show that eight articles (29.63%) mention that edible films have antimicrobial properties, six (11.11%) highlight their antioxidant capacity, five (18.52%) note their protective function, and another eight (29.63%) report that they extend the shelf life of food.

Kaur *et al*. (2024) state that edible films made from natural bioactive materials protect food from microbial effects and extend shelf life. Azizah *et al*. (2023) also report that edible films composed of fish gelatin, pectin, and essential oils yiel-

ded promising results in preserving the shelf life of meat. Han *et al*. (2023) found that edible films containing curcumin significantly extended product shelf life by reducing water activity and enhancing antioxidant capacity. Atta *et al*. (2021) highlight that edible films made with antibacterial cellulose inhibited microbial growth, thereby improving the shelf life and quality of food products.

Naseri *et al*. (2020) observed that biopolymer-based edible films enriched with essential oils effectively controlled microbial growth, maintaining the quality, freshness, and shelf life of turkey meat. Similarly, Gola *et al*. (2019) demonstrated that polyphenolic edible films formulated with carob extracts possess high antioxidant and antimicrobial capacities suitable for food packaging.

Overall, the reviewed studies reveal a wide range of biodegradable and sustainable natural sources — both plant- and animal-based — being innovatively used to extend shelf life, inhibit microbial growth, enhance product protection, and improve antioxidant capacity, thereby adding nutritional value to food products.

Additionally, eight studies (80%) report that edible films extend shelf life, thereby reducing food waste, while one study (20%) attributes this effect to their bioactive components.

Kaur *et al*. (2023) note that bioactive edible packaging effectively prolongs shelf life and reduces food waste. Adeyeye *et al*. (2023) explain that starch nanoparticles used in edible film production are biodegradable and innovative, functioning as packaging that extends shelf life and contributes to reducing food waste. Similarly, Azizah *et al*. (2023) found that edible films made with gelatin and essential oils inhibit microbial activity, extend shelf life, and prevent food spoilage and contamination. Gola *et al*. (2019) emphasize that the food industry has recently focused on developing antioxidant and antimicrobial packaging, with edible films standing out as one of the most effective solutions to extend shelf life, reduce water activity, and minimize global food waste.

CONCLUSIONS

The systematic review on the impact of edible films as an alternative food packaging solution revealed numerous benefits and challenges in their adoption. Edible films, defined as an innovative technology to extend food shelf life and enhance functional properties, are developed from various natural sources, such as cassava starch, zein, and chitosan.

The analyzed studies highlight that these films have improved tensile strength, contact angle, thermal-sealing resistance, and incorporate antimicrobial and antioxidant properties, performing comparably to conventional packaging materials. However, they face significant challenges regarding standardization, consumer acceptance, production costs, and scalability.

Future prospects are promising, with innovations in materials and production technologies expected to enhance functionality and reduce costs. Growing environmental awareness and supportive policies are also driving the development and adoption of these emerging technologies.

In conclusion, edible films represent a viable and sustainable alternative to traditional plastic packaging, with significant potential to reduce food waste and plastic pollution. Continued multidisci-

plinary collaboration and research will be key to overcoming current challenges and maximizing the benefits of this emerging sustainable technology.

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- Larrea Christian: Conceptualization; writing; statistical analysis; review and editing.
- Alvarado Daniel: Data analysis; writing.
- Callirgos David: Conceptualization; review and editing.

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