Decision matrix for the selection of biodegradable active packaging materials with antimicrobial properties.

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ABSTRACT

This project seeks to propose a decision matrix of materials with potential for the manufacture of biodegradable active packaging to prevent contamination by pathogenic microorganisms in the cheese industries of Colombia by means of a search methodology adapted from Kitchenham and a decision matrix methodology. The results found in this review reveal that in Colombia there is a lack of knowledge about packaging alternatives that exist in other countries and are applied today to products such as cheeses that have a high risk of contamination and short shelf life with conventional packaging methods, therefore, it was identified that biodegradable active packaging is a viable packaging alternative because, it acts as a protective barrier between the external conditions and the food together with an antimicrobial solution that will act against certain pathogens. Thus, a decision matrix was built with 11 film materials and 2 coating materials that were adaptable to the physicochemical properties of five Colombian cheeses.

1. Introduction

The high demand for food in low- and middle-income countries makes the application of bioactive packaging technologies essential by reducing the impact of non-biodegradable materials on the ecosystem, increasing shelf life, avoiding contamination by microorganisms in products. Dairy products and reducing food waste by improving the quality of life of people in developing countries [1]. In response to this need, the implementation of innovative packaging technologies such as active packaging, whose objective is to extend the shelf life or maintain and improve the condition of packaged foods, is of great interest since this packaging technology is designed to incorporate deliberately components that would release or remove harmful substances into or from the packaged food or the surrounding environment [2].

Colombia is the fourth-largest producer of dairy products in Latin America and the seventeenth worldwide. The dairy industry has one of the high economic participation and development potential according to DANE[1], and by 2021 this sector represented a 24.09% share of the Agricultural GDP and 1.76% of the national GDP[2] [3]. However, in Colombia, 9.76 million tons of food are discarded per year, of which dairy products correspond to 29 thousand tons per year [4]. Therefore, the implementation of biodegradable active packaging systems represents new business opportunities in the cheese industry in Colombia, which would help improve food safety, reduce waste and consequently improve people's quality of life.

Today's consumers are much more informed and aware of their needs [3] so it is necessary for the dairy market in Colombia to adapt to this consumer and take advantage of new market opportunities since most of the Colombian population continues to buy fresh cheeses as a main consumption product, mainly because they are rich in nutrients, have good affordability and are a cultural tradition of consumption. In the study on cheese consumption in Colombia (2021) it is mentioned that "Cheese consumption in Colombia has revealed that the demand for this product continues to increase in 2021, 76 thousand tons of cheese were consumed" [5].

However, the lack of information available on the application of active packaging in dairy products in Colombia makes it necessary to search for information in the literature of other countries, so that its implementation may be affected by processing parameters, such as temperature, quality, type of material and resistance, among others, specific to each country, and given that in Colombia the characteristics would be different due to environmental conditions, therefore, it is important that these materials are resistant and fit the needs of each type of cheese, to avoid errors when presenting the proposal of materials for the application of active packaging in the dairy industry in Colombia [6].

The spread of COVID-19 led to a greater use of plastic packaging materials because of the need to prioritize the safety of food and its distribution, showing the fragility of the waste management system and causing a greater dependence on single-use plastics, which is why the pandemic has put in the spotlight an old problem of excessive consumption of plastics, depletion of resources and plastic pollution, leading to the search for long-term sustainable solutions more urgently than ever [1].

The above shows that there is a need for the industry to invest in sustainable bioplastics produced from biodegradable and biobased polymers, and the interest to do so has become notable according to the number of articles published on active packaging materials in relation to the protection of dairy products such as cheese; 155 articles were published in 2010 and 248 in 2021, in different databases. Consequently, this systematic review seeks to provide information on active packaging materials for cheese and present a decision matrix tool for the classification and selection of these materials according to their durability and shelf life, which is useful for the Colombian cheese industry.

2. Methods

The following methodology was adapted from the Barbara Kitchenham guidelines for systematic literature reviews. The overall search process consists of three stages: 1) planning the review, 2) conducting the review, and 3) submitting the review report [7]. The planning consists of four steps: 1) Identification of the need for a review, 2) Specifying the research question(s), 3) Developing a review protocol, and 4) Evaluating the review protocol [8]. The following stages are conducting the review and submitting the review report, first one includes 1) Research question identification 2) Definition of inclusion

[1] The National Administrative Department of Statistics (DANE) is the entity responsible for the production of official statistics in Colombia.

[2] Gross Domestic Product (GDP) expresses the monetary value of the production of goods.

and exclusion criteria 3) Research for studies 4) Quality assessment 5) Data extraction and, 6) Synthesize data, second one requires synthesizing data and to systematically organize information to finally write the main report presented here.

Once the information was collected and synthesized, it was organized in such a way as to achieve the main objective of the project, the construction of the decision matrix. The decision matrix is a tool that will allow the Colombian cheese industry to select in a practical way the suitable material for the active packaging depending on the conditions of the cheese to be stored. The steps that were taken into account to create the matrix are follows:

1. Define the decision you want to make.
2. List the options available to make that decision.
3. Qualify the factors that must be met to make a decision.
4. Establish the weight that each factor has on that decision.
5. Calculate the scores for each factor.
6. Selection of the best material option depending on the conditions of each industry's cheese and its adaptation to its needs.

The above steps were built considering the ones that are generally used for the development of decision tools in engineering [9]. Additionally, an instruction guide was created to indicate how to use it, allowing anyone to interact with the tool.

Now, to better understand how the review was conducted, the inclusion and exclusion criteria followed in the article selection process is described below.

Inclusion criteria:

Each article should cover or relate to one of the following topics:

- Cheese pathogens control with biodegradable materials.
- Cheese preservation problems due to the conventional packaging.
- Common pathogenic microorganisms present in cheese.
- Demand for safe and long-lasting articles in the Colombian market.

Exclusion criteria:

Each article should not cover or be related to one of the following topics:

- Smart packaging systems.
- Little commercialized cheeses

The number of studies found in the literature search in databases such as Science Direct and Wiley were delimited by keywords, for example, active packaging, antimicrobial packaging and cheese. In these databases, few articles were found related to the topic of interest of "biodegradable active packaging materials with antimicrobial properties for the cheese industry" studied in this review. For this reason, it was decided not to exclude articles by databases. Approximately 96 articles were evaluated for this review between the years of 2003 to 2022, of which approximately 41 were excluded.

However, the excluded studies helped to strengthen the research equations used thereafter. The formulation of the equations for the search system are built from the keywords found in the VOSviewer tool that allows the construction of cooccurrence networks of important terms extracted from the literature (*figure 1*) and by means of Boolean logic are used in conjunction with search operators such as "OR", "AND" and "NOT" which allow the research to be delimited [10].

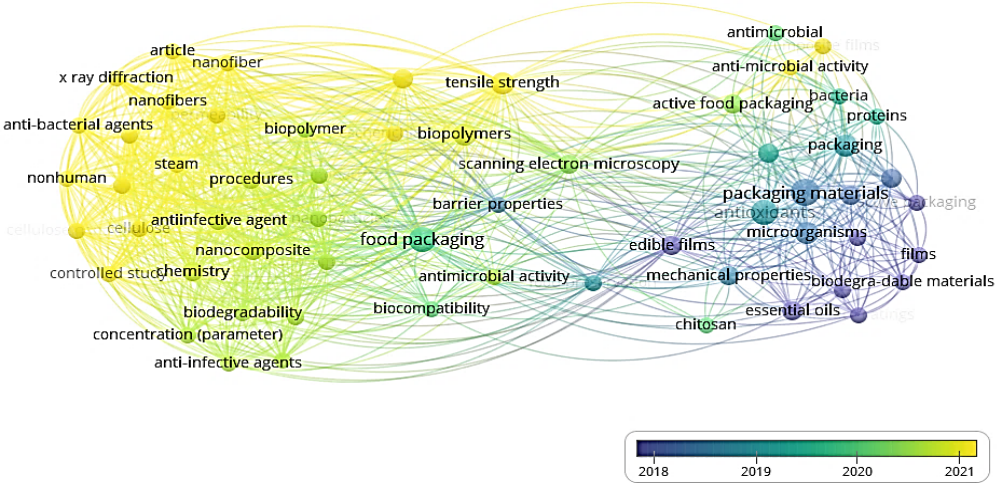

Figure 1 Cited keyword occurrence in the Scopus database about the active packaging (2018-2021)

Additionally, for the research, the percentage of articles published in each country was considered to track where more information on this topic could be found. The information from where the percentages were estimated does not include the number of published articles regarding active packaging in other countries, and that is why the figure 2 is wholly based on the five countries with most publications on the topic. During the research it was found that there are publications from different countries than those mentioned in figure 2, however, the exact number of articles published in other countries is not known.

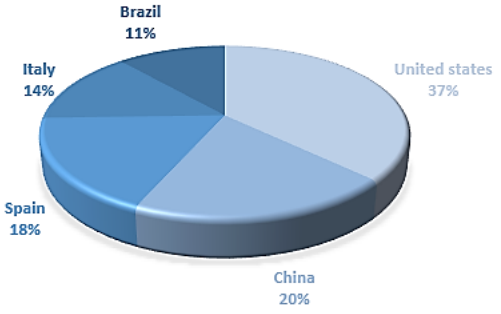

Figure 2 Percentage of published articles by country adapted from Barone et al. [1]

Subsequently, the quality of the information and evidence contained in a systematic review must be evaluated, which is as important as analyzing the data it contains, therefore, in the quality evaluation, a list of verification that contains two formats that we use to compile the information that are: the critical and systematic review and the experimental scientific articles, obtained through the JBI (Joanna Briggs Institute) critical evaluation tool, which helps to evaluate the reliability, relevance and results of the published articles. With this, it is possible to reduce some of the bias mentioned in the Cochrane Manual, which in this study would be due to the reporting of results.

Once the quality assessment is done, the data extraction was proceeded. For this review the data obtained by means of a protocol in which a data extraction form was assessed. The use of an electronic form has the added advantage of being able to combine data extraction and data entry in a single step, and to facilitate data analysis and the production of results tables for the final report.

The bibliographic manager picked to handle the articles that were researched was Mendeley, simplify the search for information and the fixing of references. Subsequently, the necessary information on the characteristics of the studies was added in the extraction form; however, data extraction is prone to human error so in that order, the review was carried out by the two main authors of this article to avoid bias, and thus reduce subjective decisions by using decision rules such as inclusion and exclusion criteria to define what information is of interest.

3. Biodegradable active packaging systems

The main objective for the food industry nowadays is to increase food shelf life, maintain food quality, and enhance food safety [11], therefore food packaging technologies have become increasingly important for the industry given the demand for healthy quality products. Food packaging seeks to maintain the quality of food, protecting it against attack from oxygen, water vapor, ultraviolet light, and both chemical and microbiological contamination, enabling foods to travel safely until it reaches the final costumer and still be wholesome at the time of consumption [12].

3.1. Active packaging

Active packaging is one of the two emerging technologies, intelligent packaging being the other, related to smart packaging. It is an innovative concept that can be defined as a packaging system in which the conditions of the package actively changes to prolong shelf life, enhance safety or sensory properties, while maintaining the quality of the product [12]–[15]. This can be achieved by applying active components such as organic acids and their salts, enzymes, fatty acids, metal nanoparticles, antibiotics, plant essential oils, antioxidants, plant volatiles, fungicides and bacteriocins in food packaging or using actively functional polymers [16].

This is particularly important in the area of fresh and extended shelf-life foods because it can reduce the moisture and weight loss, inhibit the microbial growth and maintain the sensory properties of the food over the storage time [16], thus providing better quality products to the consumer and reducing food waste by increasing shelf life of perishable food such as cheese, meet, fish and poultry.

Active packaging techniques can be divided into three categories: absorbers, releasing systems and other systems. Absorbing (scavenging) systems remove undesired components such as oxygen, carbon dioxide, ethylene, and humidity. Releasing systems actively add or emit compounds to the packaged food or into the headspace of the package, such as carbon dioxide, antioxidants and preservatives. Other systems may have miscellaneous tasks such as self-heating, self-cooling and preservation [17].

An important distinction to be made is the difference between a film material and a coating material. The coating material could be an organic compound, a thermoset or thermoplastic polymer, or a wax [18] applied to the surface, joining directly with the product, while the polymeric material is solid and is presented in sheets that surround the product without joining it.

3.2. Antimicrobial agent

Antimicrobial agents (AM) are substances that exhibit antimicrobial properties, and it encompasses different activities and microorganisms due to the specific antimicrobial mechanisms and the various physiologies of microorganisms. A broad range of antimicrobials have received attention for antimicrobial food packaging developments based on the requirement for the release elements to be nonintrusive, cheap, and compatible with the geometry and physicochemical properties of food [11].

Multiple parameters have to be taken into consideration when formulating it on food packaging; concentration, the microorganism to be attacked, the polymer in which it will be introduced, the food to be protected, storage temperature and solubility of the agent into the polymer and on the food [11].

It works through different mechanisms: 1) Mixed with food ingredients; 2) Incorporated into packaging formulation; and 3) Immersed into package headspace atmosphere. In the case of a food additive and when it is added to the polymeric formulation with the purpose to be later released into the food, AM substances are controlled as food ingredients [11].

Some of the most widely known antimicrobial agents are the naturally sourced agents; bacteriocins, antibiotics, fungicides, antimicrobial peptides and enzymes, as well as some essential oils and extracts that have proven great performance in many studies. There are also chemical agents involving organic acids, metals and inorganic acids and salts that have been used effectively in controlling a wide variety of microorganisms in food.

3.3. Biodegradable packaging

Biodegradable means that a material is capable of decomposing, in this case a biodegradable packaging is one that is capable of degrading easily by enzymatic action of microbes in a short period of time, this is due to the fact that these materials have molecules that are not as complex to process by microorganisms, compared to synthetic packaging materials that are conventionally used [19]. Considering the above, the factors that determine the biodegradability of a material are the following: chemical composition, expected condition of biodegradation of the product, non-poisonous, non-absorbable by oxygen, great capacity to resist humidity, capacity to remain in a range of temperatures and that its technical processing is economical [20].

Given that plastic packaging is currently a problem due to the contamination it has caused for many years and has increased in recent years, the sustainability of bioactive packaging depends on three principles: social, economic, and environmental. In the case of the social aspect, this type of packaging is responsible for improving the quality of life of people by reducing the use of additives used in food for its preservation and improving the durability of the packaging, with respect to the economic aspect, the reliability of the packaging will depend on its success in the distribution of the supply chain, i.e. real-time testing and that the packaging meets the right conditions for the product to maintain its properties, Finally, from the environmental principle, the handling, procurement and disposal of these bioactive packaging helps the transformation of the by-products generated in the industries that become raw material to create a value-added product that is degradable and will not require an energy process, nor additional resources for its disposal [8].

4. Current state of the market

World milk production in developing countries is approximately 500 thousand tons and in developed countries 400 thousand tons, so it

can be said that milk production in developing countries is greater than in developed countries [3]. However, world cheese production in developing countries is much lower than in developed countries, being 5 thousand tons and 20 thousand tons respectively, so it is possible that this is due to the lack of technology in cheese production, or the waste of these products due to the lack of packaging that allows the product to be preserved, prevented or inhibited from contamination.

4.1. Types of cheese that have a business opportunity

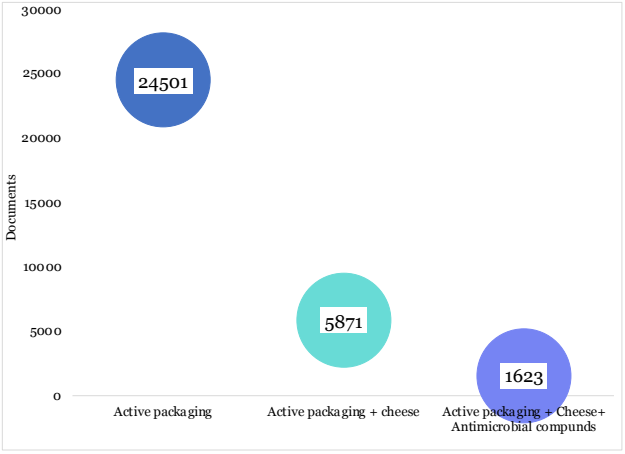

Figure 3 Number of articles published by topic of interest in the last ten years

The applicability of active packaging in the cheese has a very positive future as shown in figure 3, due to the great interest of people regarding the subject, since for today's consumers it is very important the quality of their food and safety with respect to contamination by microorganisms, which goes hand with the willingness of consumers who will pay more to receive a longer durability of their product, to contribute to sustainability and to have an antimicrobial agent that protects it from the presence of external microbes. In 2021 the consumption of cheese in Colombia was 76 thousand tons which represents a high demand that offers accordingly producers an opportunity to expand the range and presentation of products, which allows the development of other packaging technologies to be promoted [5].

The cheese in Colombia is essential to the daily diet, and its consumption has increased due to all the ways in which it can be consumed, the trend in the market to produce different varieties of cheese has been greater, currently in Colombia there are 12 kinds of cheeses that are produced in different regions, these are divided into three categories: first, non-acidic fresh cheeses such as curd cheese, farmer cheese, coastal cheese, cheese from Antioquia and ground cheese from Nariño. Second, fresh acid cheeses, such as double cream cheese, quesillo from Tolima and Huila, pear cheese, cheese from Caquetá and quesadillo. Third, mature cheeses such as paipa [21].

According to the latest Nielsen Company study on the state of the current market with respect to the consumption and sale of cheese has increased by approximately 50%, also according to the study the most relevant types of cheese focused on the Colombian market are fresh cheeses the most consumed in the domestic market, among these are the Campesino, Quesito and Cuajada; and in second place are the spun type cheeses such as Mozzarella, and mature and semi-cured cheeses are at the end of the list, where Grana Padano, Emmental or Gruyere stand out, which represents a great business opportunity [22]. Based on the study of the cheese consumption in Colombia, five fresh cheeses have been selected to be studied in this research, Antioquian, farmer cheese, cheese from Huila, Mozzarella and double cream cheese in order to narrow down the search and focus on the ones with most market potential.

A characterization of the types of cheeses mentioned above was carried out, in order to understand the conditions of storage that the active packaging must satisfy for each of them. These will be taken into account to build the decision matrix.

Table 1: Classification of types of cheese, characteristics, and storage conditions of Colombian cheeses

Type of cheese	Texture	Colombian Cheese	Fat content	Acidity	Storage conditions
Fresh	Soft	Antioquian cheese	Fatty	Non acid	Vacuum packaging. 30 days shelf life (good manufacturing practices). Storage temperature 2-4 ◦C.
	Semisoft	Farmer cheese	Semi-fat and fatty	Non acid	10-12 days shelf life (good manufacturing practices). Storage temperature 2-6 ◦C.
		Cheese (from Huila)	Semi-fat and fatty	Acid	Vacuum packaging. 20 days shelf life (good manufacturing practices). Storage temperature 2-4 ◦C.
	Semihard	Mozzarella	Semi-fat	Acid	Vacuum packaging. The material must absorb moisture. Can be preserved in whey (allows it to maintain its organoleptic properties for a longer period). Its shelf life can be extended from 7 to 10 days if storage conditions are maintained.
		Doble cream cheese	Semi-fat	Acid	Changes depending on the level of fat. Vacuum packed. Shelf life of 60 days.

Each one of the mentioned above has different physicochemical properties [23], these will determine whether a material is suitable for the cheese or not.

Table 2: Physicochemical properties of Colombian cheese

	Humidity (%)	Aw	pH	Fat (%)	Proteins (%)	Minerals (%)
Antioquian cheese	63,37	0,96	6,35	46,25	12,73	3,56
Farmer cheese	48-49	0,9	6,13-6,33	>21	17,13-18,97	3,56
Cheese (from Huila)	49-55	0,96-0,98	5,2-5,9	26-32	19-22	1,1-1,5
Mozzarella	52-61	0,97	5,2-5,4	> 17.5	19-22	3,6-3,8
Doble cream cheese	51,86	0,97	5,1-5,4	14	18,81	5,34

Own construction under [22] to [33] reference. [24][25][26][27][28][29][30][31][32][33][34][35]

4.2. Materials currently used in the dairy industry.

According with the types of cheese that have a business opportunity in Colombia, the materials currently being used in the dairy industry will be focused on such. Starting with the semi-soft and soft varieties of cheese which contain up to 80% moisture and can be further categorized in three groups: 1) ripened by bacteria (e.g.) 2) ripened by surface (e.g.) 3) internally mold ripened (e.g.) [2]. Internally mold ripened cheese should be packed in O_2, CO_2 and water permeable packages such as polystyrene, polyvinyl chloride or thermoformed packages for optimum mold growth [36]. Externally ripened cheese packaging should take place right after the mold has frown to certain extent and it requires permeability to O_2 and H_2O to avoid growth of anaerobic proteolytic bacteria and moisture condensation inside cheese pack, for this reason, oriented polypropylene is the suitable material [2].

For the fresh or unripened cheeses a different kind of material is needed due to the moisture content and high chances of dehydration or whey expulsion owing to their high-water activity (Aw). Some of the suitable packaging options are injection molded HDPE or PP packages with side slits for whey drainage, paraffin or PVDC (polyvinylidene chloride) coated paper and LDPE or PP laminated aluminum (Al) foil (7–20 μm) [2]. Although some of the materials mentioned above have proven to be effective against microorganisms once an additive is incorporated, they are not biodegradable.

There are few active and intelligent packaging options available for cheeses. Antipack™ AF from the company Handary in Belgium (A, *figure 4*), is an active antifungal biodegradable film used to prevent

mold growth by releasing gradually fermented sugar activities from the film onto the surface of solid foods such as semi-hard cheese during the shelf life. The product is based on advanced controlled-released technology that combines biodegradable hydrophobic Polylactic Acid (PLA) and hydrophobic fungal chitosan containing-fermented sugar to produce health, convenient, cost-efficient antimicrobial film [21].

Another example of bioactive packaging systems used nowadays is Lactips, a start-up company based in France created an edible plastic film from casein (C, *figure 4*). Lactips seeks to offer a clean and eco-responsible plastic, from milk protein granules, promoting the use of milk not suitable for consumption and offering a solution to the use of petroleum-derived plastics. the Lactips project aims to change behaviors and introduce a product that is safer for the consumer and more respectful of the environment in the food industry [37].

Figure 4 Commercially available active and intelligent packaging systems for cheese. (A) biodegradable active antifungal film Antipack™ AF, Handary, Brussels, Belgium (B) antimicrobial films with natamycin, VGP SL®, Barcelona, Spain [2] *(C) edible plastic films developed from casein by Lactips, France.*

4.3. Microorganisms present in cheeses

Pathogenic microorganisms present in cheeses made in Colombia are generally due to lack of hygiene. According to a study by the Javeriana University that was carried out in 20 selected establishments (supermarkets, stores, market places and fast food outlets), the most common causes of the proliferation of pathogens are: supermarkets sell products with registered trademarks and cheeses they are refrigerated Unlike shops, tobacconists and market places, in some places the cheese is left uncovered and therefore exposed to insects attracted by the smells and the same knife is used to cut the cheeses and meats. Vendors in marketplaces, shops and tobacconists handle money and cheese without taking measures to prevent contamination. Most cheeses do not have a sanitary registration. In the marketplaces, in a single stall you can find the cheeses next to the unrefrigerated chickens [38]

Table 3: Pathogenic microorganisms in cheese

Types of cheese	Microorganism present	Diseases that can be transmitted
Semi-hard and semi-soft cheeses Fresh cheeses (curd cheese, mozzarella cheese)	*Penicillium sp. (microfungi)*	It contains a large number of toxigenic species and its capacity to produce different mycotoxins is superior to that of any other fungal genus, causing from ataxia to death by spastic paralysis
	Salmonella spp (bacterium)	This is the most important bacterium of foodborne diseases and causes salmonellosis, a disease associated with intestinal problems (such as diarrhea and fever), which can affect any person indiscriminately [39]
Quesillo	*Listeria monocytogenes (bacterium)*	The disease it causes (listeriosis) has a mortality rate that varies between 20% and 30% and is therefore considered a public health problem. However, its attack rate is low, and it mainly affects pregnant women, neonates, and people with weak immune systems [39].
	E. Coli (bacterium)	These cause diarrhea and vomiting, although septic shock, hepatitis, headache, fever, and double vision can also be observed [39].
Double cream cheese	*Chrysosporium spp. (Mold)*	It can cause skin infections and onychomycosis; its mortality rate is high.
	Alternaría spp (Mold)	Mycotoxin production, ingestion, inhalation, or dermal absorption of these compounds causes adverse health effects in animals and humans, giving rise to a group of diseases called mycotoxicosis (cutaneous alternariosis).

In this sense, the causes are due to the lack of knowledge about the good manufacturing practices (GMP) and the lack of innovative alternatives for food packaging that allow large and small cheese-producing companies to obtain higher profits. maintaining the quality of your product, therefore, it is important to know the causes and correct these bad practices and implement new storage technologies that allow the preservation of the organoleptic properties, and that the durability of the product is not affected by the lack of care or monitoring proper cold chain.

5. Efficacy of biodegradable active packaging material

In order to better understand what effectiveness of a material in controlling microorganisms means, a brief description is made of the two parameters to be taken into account when evaluating a packaging material. Both must be considered altogether to understand the factors that will affect the quality of the final product.

5.1. Durability factors for active packaging materials

Durability is defined as the ability of a material to remain serviceable in the surrounding environment during the useful life without damage or unexpected maintenance [40].

It is important to clarify that in the construction of the decision matrix it is not intended compare the methods used between the different materials since there are all kinds of tests done to achieve the same purpose [41]. For example: the raw material obtained for each one is different and therefore, the evaluations will depend on the source. However, a wide search was made for all the parameters that are studied in each material and that probably define the durability of the active packaging, which are:

- **Tensile strength**, **elongation percentage** and **tear strength** are parameters that packaging materials must meet, as they need to be adapted to protect the product during prolonged storage and transport.
- Parameters such as **oxygen**, **CO_2**, **H_2O**, **light**, and **aroma** are studied to avoid moisture loss, since most cheeses have high humidity and what is desired is to avoid drying of the surface.
- **Migration and microbial growth**, it is important that the materials that are biodegradable have an antimicrobial agent since the sources of these materials are generally sources of energy for microorganisms which can be a risk against the growth of mold and undesirable bacteria in the package or microbial migration to the outside that contaminate food, for this reason, you must establish the concentration limits of migrating agents and which is the material to use for the packaging film.
- **Temperature and chemical resistance**, resistance properties will change depending on fat content, exposure to chemicals and the type of antimicrobial agent used depending on the material.
- **Transparency**, both the product and the packaging are color tested to determine if the material or product does not transfer components that generate mutual damage.
- Of the **molding properties of** the packaging design will depend on its production
- **Quantity of cheese and depth of the container will** define how long the packaging must last according to the capacity needed and according to the characteristics of the cheese.

5.2. Shelf-life factors for active packaging materials

Shelf-life can be defined as the estimated duration that an object can have, correctly fulfilling the function for which it has been created.

According to Science Direct it is defined as the period of time a product can be stored without becoming unsuitable.

Thus, the self-life of a product will be affected by some factors listed below. Acknowledging this will help to better understand what is needed to be taken into consideration when evaluating an active packaging material and its efficacy.

- The presence of **residual O2** in the headspace of packages is one of the most critical factors limiting the shelf life of packaged food products. Oxidative deterioration can cause considerable detrimental effects on O2-sensitive food constituents, which in turn causes changes in sensory qualities and destroys nutritional values. This space also facilitates the growth and activities of aerobic bacteria, mold and insect infestation leading to foodborne illnesses and economic losses due to food waste [42].

- **Moisture control** in packaged food products should be strategically designed to regulate moisture adsorption of dry products, desorption of water-rich foods or migration of multi-domain foods within the tolerable moisture range to avoid hysteresis and moisture-related spoilage [42].

- **Humidity control** helps buffer the optimum relative humidity of the package to reduce moisture loss and retard excess moisture in the package headspace and interstices where microorganisms can grow [42].

- Preserving the quality of cheese depends to a large extent on its **protection against ultraviolet light**; therefore, optical properties such as UV absorbance/transmission, color and transparency of packaging materials are strategically vital. Protecting the contents from ultraviolet light preserves the cheese's nutrients, minimizes lipid oxidation and limits discoloration and off-flavors [16].

- **Contamination, subsequent growth and activities of pathogenic or spoilage microorganisms** are the most detrimental factor determining the shelf life of processed food products. In fact, post-processing contamination is a major cause of foodborne illness and associated product recalls [42].

- In controlled atmosphere packaging (MAP), **high levels of** bacteriostatic and fungistatic **CO2** are commonly used to extend the lag phase of growth and suppress the growth rate during the logarithmic growth rate of normal spoilage microorganisms (aerobic, gram-negative psychotropic bacteria) on the surfaces of fresh meat, poultry, cheese or bakery products. However, a high level of CO2 can stimulate the growth of yeasts and lactic acid bacteria.

6. Decision matrix construction process

6.1. Material characterization

In order to achieve the objective of proposing a decision matrix for the selection of materials with potential application in biodegradable active packaging to prevent contamination by pathogenic microorganisms in the Colombian cheese industry, the following specific objectives were proposed: To identify biodegradable active packaging materials with potential use in the control of pathogens in the Colombian cheese industry and to systematically classify the materials according to their effectiveness in the control of microorganisms, so the following is a description of the selection procedure and classification of materials.

First, a collection was made of the materials described in the previously selected articles (*Annex 1*) and an initial selection was made based on their biodegradability and the result of each study, evaluating that the proposed material was ready and did not require further study to be used. After this first filter, 42 materials were reduced to 32. This allowed observing that the studies had a variation in the tests performed on each material, i.e., different methods were used to determine certain parameters, so each one was reviewed in detail. After characterizing the materials and performing an analysis, another filter was made to eliminate those that had unsatisfactory results in the sensory evaluation, those that were repeated in different articles and/or whose shelf life decreased with active packaging, so that 32 materials were reduced to 25 and these were the ones that went to the final stage of evaluation in the decision matrix, leaving 11 polymeric materials (*Table 4*) and 2 coatings (*Table 5*).

Table 4: Description of final polymeric materials

Number	Material	Antimicrobial agent	Reference
1	Chitosan	Moringa oil	[43]
2	Starch/Halloysite/ nanocomposite films	Nisin	[44]
9	Triticale flour with bacteriocin-like substance	The material has antimicrobial properties	[45]
10	Semolina flour and nanocomposites (zinc oxide and kaolin)	The material has antimicrobial properties	[46]
13	Chitosan	Natamycin	[47]
14	Whey protein isolate nanofibers	Carvacrol	[48]
15	Alginate	Oregano/rosemary essential oils	[49]
16	Chitosan / Whey protein	The material has antimicrobial properties	[50]
17	Sodium alginic acid	Silver montmorillonite nanoparticles	[51]
26	Sodium alginate	Potassium sorbate	[52]
31	Biodegradable film based on fish gelatin	*Lepidium sativum* extract	[53]

The numbers are not consecutive due to multiple filtering processes, the original numbering was kept to facilitate the search process in our database.

Table 5: Description of final coating materials

Number	Material	Antimicrobial agent	Reference
18	Whey protein isolate	*Bunium persicum* essential oil/lactoperoxidase system	[54]
21	Whey protein isolate/alginate	Ginger essential oil	[55]

Due to the differences between the materials and the coatings, they had to be evaluated separately, so a decision matrix was made for each one and in the case of the coatings, the mechanical properties and appearance factor was eliminated since they would not apply in this case. This clarification is important in order to take into account why these materials were divided and how they were evaluated.

6.2. Study factors

Now, after the second filter where the materials were characterized according to the tests carried out on each material, it was possible to corroborate what the results in section 5 showed in relation to the relevant factors in the evaluation of packaging materials. Each of these factors was assigned a weight according to its importance in the packaging of cheeses, i.e., how important is its effect on the adequate conservation of cheeses packed in active containers.

In accordance with the above, each factor was evaluated in the following way according to what was analyzed when evaluating each review:

- **Sensory evaluation (weight 6):** its results determine the acceptability, usefulness and application of the product by the consumer.

- **Microbial control (weight 5):** the packaging must comply with the microbiological requirements of NTC 750 and must also ensure microbial control once the cheese is packaged and distributed, since this will have a significant effect on the quality of the product and will prevent the transmission of diseases caused by pathogenic microorganisms.

- **Mechanical properties (weight 4):** the mass transfer that can occur due to product moisture and the antimicrobial agent solution will probably influence the strength of the material which can cause deformation of the material and thus contamination of the product.

- **Appearance of the package (weight 3):** appearance tends to be related to the quality of the product, so its color is considered by consumers as an indicator of the state in which the product is likely to be.

- **Statistical analysis (weight 2):** helps us to identify which statistical method they used to analyze their data and the significance

of the results. In this case we only evaluate how reliable the study is according to the data treatment.

- **Ability to survive the breakage of the cold chain (weight 1):** this was determined according to the observations made in all the studies where only some materials could tolerate a certain temperature range and still be able to preserve the organoleptic properties of the cheese, however, this is not the focus of the study and it is an improvement that the material may have, so its relevance is not so significant.

6.3. Tables of physicochemical properties of cheeses

The selection of materials was carried out using three different tables, the decision matrix, a table of physicochemical properties tolerable by the materials and the table of physicochemical properties of each of the cheeses with business opportunity mentioned in section 4.1. The following is a detailed description of the physicochemical properties tables.

First, the table of physicochemical properties of Colombian cheeses (*Table 2*) was constructed in order to have a clear understanding of the ranges that the materials had to meet in order to be suitable for implementation in the packaging of the selected cheeses. Then we proceeded to evaluate each article in order to find the physicochemical properties tolerable for each material, however, not in all the studies these properties were explicit, therefore we started from the assumption that if the result had been satisfactory for the cheese under study, therefore the material would support the physicochemical properties of that cheese, therefore the table was completed with the ranges of physicochemical properties of the cheeses that were studied in each of the materials. For example, in material 2 the cheese minas frescal was packed, therefore, the physicochemical properties of this cheese were searched to see the tolerance ranges of material 2.

Once these two tables were created, a comparison of properties could be made in order to match materials with Colombian cheeses. Then, it was taken as a parameter that the properties of the material had to match at least 4 properties of the Colombian cheese and in this way each one of the materials was classified with the respective cheese to which it would be applicable. However, in this process, 2 coatings had to be discarded because the tolerable physicochemical properties did not coincide with those of the selected cheeses.

6.4. Decision matrix construction

For the construction of the materials decision matrix, the "weight" of each factor was determined with a value between 1 and 6 according to its influence in all the studies to determine the acceptability of the material. Each material has an evaluated property with a weight ranging from 1-6, where its weight is 1: not important, 2: not very important, 3: moderately important, 4: important, 5: very important, 6: extremely important. On the other hand, the "result" is a value from 0-5 which refers to how good the result of the study factors was in each material, being 0: very bad, 1: bad, 2: fair, 3: acceptable, 4: good, 5: excellent.

Similarly, a matrix similar to the one described above was made for the coatings, which, as mentioned above, does not include the factor of mechanical properties or the appearance of the packaging, so the weights for each factor are as follows. Sensory evaluation: weight 4; microbial control: weight 3; statistical analysis: weight 2; ability to survive breakage of the cold chain: weight 1.

The calculation of the matrix consists of multiplying the "weight" of the factor by the "result" of that factor in the material and then adding the different multiplications as shown in Table 6.

Table 6: Example of decision matrix calculation

Material	Sensory evaluation	Microbial control	Total
Weight	6	5	
X	3	5	6*3 + 5*5

This is just meant to be an example as to how the calculation of the decision matrix was made. The real numbers are shown in Annex 2.

An important aspect to take into account after evaluating each material was that excellent materials were found that, because they were not evaluated in any of the study factors, had a lower score than others. An example of this was material 9 of triticale flour with bacteriocin, which had a score of 5 in all the study factors except in the sensory evaluation, since no studies of organoleptic properties were carried out on the cheese packed in the material, and since this was the factor with the greatest weight, the score of the material was strongly affected. The table (final result table) shows that material 9 is after 2 materials (1 and 10) in which 1 had a barely acceptable sensory evaluation and material 10 had no information about the appearance of the packaging or its ability to survive a break in the cold chain.

Due to the above, we invite further studies of these materials taking into account all the factors previously mentioned, since this will allow us to have a broader vision of their effectiveness in the preservation of cheeses.

6.5. Final result

Once the decision matrix (*Annex 2*) was completed, the total scores of the matrix were used to rank each of the materials from best to worst. The property tables made it possible to match the materials with each cheese; however, the matrix made it possible to prioritize each material according to all the other study factors that must be taken into account when selecting an active packaging**.**

Table 7: Result after match and sorting of decision matrix

Type of cheese	Materials in order	Coatings in order
Antioquian cheese	13, 16	
Farmer cheese	15, 31, 26, 2, 17	
Cheese (from Huila)	10, 26, 2	18, 21
Mozzarella	1, 10, 9, 26, 17, 14	18, 21
Double cream cheese	1, 10, 9, 26, 17, 14	18, 21

The numbers of each material are referenced to Table 4 and 5.

With the previous results it was possible to create an interactive matrix to determine the best material for certain physicochemical properties, the tool has a user guide and will only give an answer if the values are in the range of physicochemical properties tolerable by the materials, otherwise it will not propose any material. You can access the tool through the link below.

https://www.bioactivepack.com/

Since the types of cheese and environmental conditions of the studies evaluated are not the same as the ones we have in Colombia, the materials and coatings showed in the interactive tool may not work as well or can cause adverse effects on it. The decision matrix is yet to be validated. It is also important to clarify that the decision matrix was originally created having the five Colombian cheeses originally selected in mind: Antioquian, farmer cheese, cheese from Huila, Mozzarella and double cream cheese, so although it works for a various range of values it may still contain error due to the reference to which it was created.

7. Good handling practices on the efficiency of materials

(EN PROCESO DE CORRECCIÓN)

In the studies reviewed, it was found that some of these studies evaluate the effect of the innocuousness of the process in the manufacturing stage and how relevant is its influence, so they have found that not exercising good manufacturing practices accelerates the contamination process, not only of the product but also of the packaging when it comes from a biological source [41].

Because of the above, this paper aims to clarify what can happen if these materials are applied and do not have good practices, since in Colombia there is a problem with respect to non-compliance with hygiene standards, according to the study "Against pathogens in cheese: a question of good practices" Javeriana University [38], found that this problem usually occurred in small producers where the cheese is wrapped in foil and often do not have health registration, in this study, found that: in supermarkets the cheeses are refrigerated, unlike in stores or market places, also in some places the cheese is left uncovered, a single knife is used to cut both cheeses and meats and they are stored next to other meat products causing contamination of the cheese.

The implementation of good manufacturing practices (GMPs) and standard sanitation operating procedures (SSOPs) is considered the first step in the development of the hazard analysis and critical control point (HACCP) system in food industries. The implementation of GMPs and SSOPs require investments to improve the hygienic design of equipment and facilities, control of operations, maintenance and sanitation practices, personal hygiene, transportation and training in order to ensure the fabrication of safe foods [56]. Studies carried out assessing the costs involved in the implementation of GMP in dairy industries such as Cusato et al. research, conclude that the application

of HACCP presented an adequate cost-benefit relationship, which would improve with the passage of time and with the improvement and sedimentation of the culture of food safety in the company.

Although the cost-benefit of the implementation of these practices is positive, it is understood that small products may have greater difficulty in incurring the costs that this represents, for which it is recommended to follow up on the investments made by governmental entities and the companies themselves to promote the sector's growth, especially investments in physical infrastructure and equipment that may become obsolete due to their useful life [57].

It is suggested that the cheeses are kept refrigerated at approximately 4°C in its original wrapping until ready to use. It is best to store cheese in a refrigerator drawer, so it does not pick up off-flavors from other foods [58] and to throw out soft cheeses that have been at room temperature for more than four hours. It is also suggested to always carefully wash kitchen utensils (such as knives, containers) with which these products are to be handled [38].

It is important to also disclaim that *Listeria monocytogenes*, one of the microorganisms that endanger cheese safety, can survive to refrigeration, thereby, Possas et at. state that the monitoring of good practices in the manufacture of cheeses is required to make cheese safe. It must be considered, however, that each type of cheese is different, so the bacteria's behavior can also vary. For example, in fresh cheeses such as the ones in this review, *L. monocytogenes* could be able to proliferate during storage at room temperature, reaching high levels of contamination if handling and storage conditions are not adequately monitored, when the results were that the bacteria actually survived better at lower storage temperature in the study carried out by the authors above [59].

The best if used by date tells you how long the product will keep its best flavor or quality. The term is not a safety date. Best if used by dates are general guidelines, as some foods may deteriorate more quickly and other foods may last longer than the times suggested.

Accordingly, if it is desired to apply this type of technology, such as biodegradable active packaging, and if it is intended to maintain the efficiency of the packaging or that these do not exceed the established limit of microorganisms in the cheeses, producers must guarantee that hygienic conditions are met, both in the place where the product is made, the processing of the product, the people who have direct or indirect contact, and that the cold storage chain is not broken.

8. Conclusions

Some biodegradable active packaging materials with potential use in the control of pathogens in the Colombian cheese industry were identified, however, it is concluded that although these materials are able to reduce most of the microbial propagation, their efficiency is related to good manufacturing practices and require its application on small producers in Colombia to ensure food safety at all times.

The materials were systematically classified according to their durability and effectiveness in the control of microorganisms and from this it was possible to build and propose a decision matrix for the selection of materials with potential application in biodegradable active packaging to prevent contamination by pathogenic microorganisms in the Colombian cheese industry, with a total of 12 materials and 2 coatings. Additionally, an interactive tool was built online in order to make the information accessible to cheese producers.

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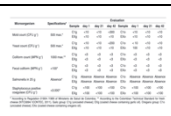
Annexes

1.

Characterization of materials							
Type of cheese	**Packaging**	**Antimicrobial agent**	**Microoganism**	**Biodegradable**	**Origin**	**Applicability**	**References**
Fresh cheese	Pululan nanofibers	Nisin	*L. mesenteroides L. monocytogenes S. Typhimurium*	Yes	Mexico	It is not yet on the market and is lacking tests to prove higher inhibition of its antimicrobial activity.	S. Torres-Giner et al., "Advancements in Biodegradable Active Films for Food Packaging: Effects of Nano/Microcapsule Incorporation," Foods 2022, Vol. 11, Page 760, vol. 11, no. 5, p. 760, Mar. 2022, doi: 10.3390/FOODS11050760
Fresh hard cheese	Chitosan	Moringa oil	*L. monocytogenes and S. aureus*	Yes	China	Not yet on the market but ready.	S. Torres-Giner et al., "Advancements in Biodegradable Active Films for Food Packaging: Effects of Nano/Microcapsule Incorporation," Foods 2022, Vol. 11, Page 760, vol. 11, no. 5, p. 760, Mar. 2022, doi: 10.3390/FOODS11050760
Soft cheese	Starch/halloysite/nanocomposite films	Nisin	*L. monocytogenes*	Yes	Brazil	This is a study showing that a group of biopolymers improves the protective properties of the active packaging. However, it is not yet on the market but it is ready.	S. Torres-Giner et al., "Advancements in Biodegradable Active Films for Food Packaging: Effects of Nano/Microcapsule Incorporation," Foods 2022, Vol. 11, Page 760, vol. 11, no. 5, p. 760, Mar. 2022, doi: 10.3390/FOODS11050760
Cheddar cheese	Chitosan	Nisin-silica liposomes	*L. monocytogenes*	Yes	China	Not yet on the market but ready.	S. Torres-Giner et al., "Advancements in Biodegradable Active Films for Food Packaging: Effects of Nano/Microcapsule Incorporation," Foods 2022, Vol. 11, Page 760, vol. 11, no. 5, p. 760, Mar. 2022, doi: 10.3390/FOODS11050760
Fresh semi-hard cheese	Zein nanofibers	Essential oils of Romarinus officinalis and Laurus nobilis.	*S. aureus and L. monocytogenes*	Yes	Spain	Not yet on the market but ready.	*Z. Aytac et al., "Development of Biodegradable and Antimicrobial Electrospun Zein Fibers for Food Packaging," ACS Sustain. Chem. Eng., vol. 8, no. 40, pp. 15354–15365, Oct. 2020, doi: 10.1021/ACSSUSCHEMENG.0C05917/SUPPL_FILE/SC0C05917_SI_001.PDF. *S. Torres-Giner et al., "Advancements in Biodegradable Active Films for Food Packaging: Effects of Nano/Microcapsule Incorporation," Foods 2022, Vol. 11, Page 760, vol. 11, no. 5, p. 760, Mar. 2022, doi: 10.3390/FOODS11050760
Cheese	Chitosan nano particles	Clove oil	*E. Coli and S. aureus*	Yes	Ireland	It is ready to be used in the market.	S. Sharma, S. Barkauskaite, B. Duffy, A. K. Jaiswal, and S. Jaiswal, "Characterization and Antimicrobial Activity of Biodegradable Active Packaging Enriched with Clove and Thyme Essential Oil for Food Packaging Application," Foods 2020, Vol. 9, Page 1117, vol. 9, no. 8, p. 1117, Aug. 2020, doi: 10.3390/FOODS9081117.
Semi-hard cheese	PLA	Riboflavin	*E. Coli*	Yes	Denmark	Ready for use with riboflavin, PLA is already on the packaging market.	Jakobsen, M., Holm, V., & Mortensen, G. (2008). Biobased packaging of dairy products. Environmentally Compatible Food Packaging, 478–495. https://doi.org/10.1533/9781845694784.3.478
Cheese	Chitosan	Garlic oil/Nisin/potassium sorbate/stearic acid	*B. cereus, E. coli, S. typhimurium, S. aureus and L. monocytogenes*	Yes	India	Not yet on the market but ready.	Malhotra, B., Keshwani, A., & Kharkwal, H. (2015). Antimicrobial food packaging: Potential and pitfalls. Frontiers in Microbiology, 6(JUN), 611. https://doi.org/10.3389/FMICB.2015.00611/BIBTEX
Cheese	Chitosan	Natamycin	*A. niger*	Yes	Portugal	It has not been launched on the market and studies are lacking.	Galotto, M. J., Guarda, A., & Dicastillo, C. L. de. (2015). Antimicrobial Active Polymers in Food Packaging. Functional Polymers in Food Science: From Technology to Biology, 1, 323–353. https://doi.org/10.1002/9781119109785.CH10
Cheese	Poly-L lysine	Lysozyme	*L. monocytogenes, E. coli y S. aureus*	Yes	Chile	It has not been launched on the market and studies are lacking.	Galotto, M. J., Guarda, A., & Dicastillo, C. L. de. (2015). Antimicrobial Active Polymers in Food Packaging. *Functional Polymers in Food Science: From Technology to Biology*, *1*, 323–353. https://doi.org/10.1002/9781119109785.CH10
Slices of semi-hard white cheese	Triticale flour with bacteriocin-like substance	packaging has antimicrobial properties	*Listeria spp*	Yes	Brazil	He has all the studies but has not gone to the market.	Salvucci, E., Rossi, M., Colombo, A., Pérez, G., Borneo, R., & Aguirre, A. (2019). Triticale flour films added with bacteriocin-like substance (BLIS) for active food packaging applications. Food Packaging and Shelf Life, 19, 193–199. https://doi.org/10.1016/J.FPSL.2018.05.007
Mozzarella cheese in cubes	Semolina flour and nanocomposites (zinc oxide and kaolin)	packaging has antimicrobial properties	*E. coli, S. aureus, C. albicans y A. niger.*	Yes	Malasia	Effective but not yet on the market.	Jafarzadeh S, Rhim JW, Alias AK, Ariffin F, Mahmud S. Application of antimicrobial active packaging film made of semolina flour, nano zinc oxide and nano-kaolin to maintain the quality of low-moisture mozzarella cheese during low-temperature storage. J Sci Food Agric. 2019 Apr;99(6):2716-2725. doi: 10.1002/jsfa.9439. Epub 2019 Jan 25. PMID: 30350410.
Sliced mozzarella cheese	Cellulose acetate and pink pepper essential oil	packaging has antimicrobial properties	*L. monocytogenes y S. aureus*	Yes	Brazil	Toxicological tests still need to be performed to confirm the safety of the material, it is not ready.	Dannenberg, G. da S., Funck, G. D., Cruxen, C. E. dos S., Marques, J. de L., Silva, W. P. da, & Fiorentini, Â. M. (2017). Essential oil from pink pepper as an antimicrobial component in cellulose acetate film: Potential for application as active packaging for sliced cheese. LWT - Food Science and Technology, 81, 314–318. https://doi.org/10.1016/J.LWT.2017.04.002
Young white cheddar cheese	Cellulose-based packaging (bioactive inserts) used with modified atmosphere packaging	Nisin	*L. innocua, S. aureus*	Yes	Ireland	It already has all the studies, it is more than ready to go to the market (in this case the packaging already exists, but it has not been applied with the concentrations of antimicrobial used in the article for greater inhibition).	Ibarra-Sánchez, L. A., El-Haddad, N., Mahmoud, D., Miller, M. J., & Karam, L. (2020). Invited review: Advances in nisin use for preservation of dairy products. Journal of Dairy Science, 103(3), 2041–2052. https://doi.org/10.3168/JDS.2019-17498
Double cream cheese	Chicory starch/microcrystalline cellulose	Garlic/Oregano oils		Yes	Colombia	Not yet on the market but ready.	Molina-Hernández, J. B., Echeverri Castro, A., Martinez-Correa, H. A., & Andrade-Mahecha, M. M. (2020). Edible coating based on achira starch containing garlic/oregano oils to extend the shelf life of double cream cheese. Revista Facultad Nacional de Agronomía Medellín, 73(1), 9099–9108. https://doi.org/10.15446/rfnam.v73n1.75234
Soft cheese	Chitosan	Natamycin	bacteria, yeast, mold, coliforms	Yes	Iran	It is not yet on the market but is ready with a note that it can be used in other cheeses.	Nottagh, S., Hesari, J., Peighambardoust, S.H. et al. Effectiveness of edible coating based on chitosan and Natamycin on biological, physico-chemical and organoleptic attributes of Iranian ultra-filtrated cheese. Biologia 75, 605–611 (2020). https://nebulosa.icesi.edu.co:2144/10.2478/s11756-019-00378-w
Soft cheese	Sodium alginate	Turmeric powder	lactic acid bacteria, coliforms	Yes	Brazil	The antimycobacterial was not effective in reducing coliforms, not ready	Olivo, P.M., Da Silva Scapim, M.R., Miazaki, J. et al. Sodium alginate with turmeric coating for ripened cheeses. J Food Sci Technol 57, 2364–2369 (2020). https://nebulosa.icesi.edu.co:2144/10.1007/s13197-020-04438-x
Fresh soft cheddar cheese	Whey protein isolate nanofibers	Carvacrol	*L. monocytogenes, S. aureus, S. enteritidis and E. coli*	Yes	China	Not yet on the market but ready.	Wang, Q., Yu, H., Tian, B., Jiang, B., Xu, J., Li, D., . . . Liu, C. (2019). Novel edible coating with antioxidant and antimicrobial activities based on whey protein isolate nanofibrils and carvacrol and its application on fresh-cut cheese. Coatings, 9(9) doi:10.3390/COATINGS9090583
Soft cheese	Agar	Bacteriocins	*L. monocytogenes*	Yes	Argentina	Works but suggest further research to determine toxicological and sensory properties of coated cheeses.	M. Virginia Guitián, Carolina Ibarguren, M. Cecilia Soria, Paula Hovanyecz, Claudia Banchio, M. Carina Audisio, Anti-Listeria monocytogenes effect of bacteriocin-incorporated agar edible coatings applied on cheese, International Dairy Journal, Volume 97, 2019, Pages 92-98, ISSN 0958-6946, https://doi.org/10.1016/j.idairyj.2019.05.016.
Fresh cheese	Alginate	Oregano/rosemary essential oils	*Salmonella sp, L. monocytogenes*	Yes	Brazil	Not yet on the market but ready.	Pieretti, G. G., Pinheiro, M. P., Scapim, M. R. da S., Mikcha, J. M. G., & Madrona, G. S. (2019). Effect of an edible alginate coating with essential oil to improve the quality of a Fresh cheese. Acta Scientiarum. Technology, 41(1), e36402. https://doi.org/10.4025/actascitechnol.v41i1.36402+W25:W26
Ricotta cheese	Chitosan with whey protein film	Chitosan	psychrotrophic and mesophilic microorganisms and lactic acid bacteria	Yes	Italy	It is not yet on the market but is ready with a note that it can be used in other cheeses.	Prospero Di Pierro, Angela Sorrentino, Loredana Mariniello, Concetta Valeria L. Giosafatto, Raffaele Porta, Chitosan/whey protein film as active coating to extend Ricotta cheese shelf-life, LWT - Food Science and Technology, Volume 44, Issue 10, 2011, Pages 2324-2327, ISSN 0023-6438, https://doi.org/10.1016/j.lwt.2010.11.031. (https://www.sciencedirect.com/science/article/pii/S0023643810004081)
Soft cheese (Fior di	Sodium alginic	Silver-montmorillonite	*Pseudomonas spp.*	Yes	Italy	Not yet on the market but	D. Gammariello, A. Conte, G.G. Buonocore, M.A. Del Nobile, Bio-based nanocomposite coating to preserve quality of Fior di

							2011, Pages 5298-5304, ISSN 0022-0302, https://doi.org/10.3168/jds.2011-4161.
Semi-hard cheese	Galactomannan /chitosan	Chitosan	Mesophilic bacteria	Yes	Portugal	It works but they suggest further research to improve on coating application methods to have a more uniform distribution of the coating on the surface of the cheese.	Miguel A. Cerqueira, Maria J. Sousa-Gallagher, Isabel Macedo, Rocio Rodriguez-Aguilera, Bartolomeu W.S. Souza, José A. Teixeira, António A. Vicente, Use of galactomannan edible coating application and storage temperature for prolonging shelf-life of "Regional" cheese, Journal of Food Engineering, Volume 97, Issue 1, 2010, Pages 87-94, ISSN 0260-8774, https://doi.org/10.1016/j.jfoodeng.2009.09.019.
Hard cheese (gouda)	Tapioca starch	Natamycin and Nisin	*S. cereviseae, L. innocua*	Yes	Argentina	Works but it is not ready to go to market.	Sofía Berti, Carolina P. Ollé Resa, Florencia Basanta, Lía N. Gerschenson, Rosa J. Jagus, Edible coatings on Gouda cheese as a barrier against external contamination during ripening, Food Bioscience, Volume 31, 2019, 100447, ISSN 2212-4292, https://doi.org/10.1016/j.fbio.2019.100447.
Hard cheese (gouda)	Whey protein isolate	Bunium persicum essential oil/lactoperoxidase system	Gram-positive and gram-negative bacteria	No	Iran	Not yet on the market but ready.	Saravani, M, Ehsani, A, Aliakbarlu, J, Ghasempour, Z. Gouda cheese spoilage prevention: Biodegradable coating induced by Bunium persicum essential oil and lactoperoxidase system. Food Sci Nutr. 2019; 7: 959– 968. https://doi.org/10.1002/fsn3.888
Semi hard cheese (low fat cut cheese)	Sodium alginate, tangerine fiber, Tween 80	Oregano essential oil	*S. aureus*, psychrophilic bacteria, yeasts or molds	Yes	Spain	Not yet on the market but ready.	María Artiga-Artigas, Alejandra Acevedo-Fani, Olga Martín-Belloso, Improving the shelf life of low-fat cut cheese using nanoemulsion-based edible coatings containing oregano essential oil and mandarin fiber, Food Control, Volume 76, 2017, Pages 1-12, ISSN 0956-7135, https://doi.org/10.1016/j.foodcont.2017.01.001.
Semi hard cheese (goat cheese)	Chitosan	Oregano/rosemary essential oils	Mucor and Penicillium fungi	Yes	Spain	works for cheese mushrooms where the migration of EO compounds (essential oils) is not objectionable.	Cano Embuena, A.I., Cháfer Nácher, M., Chiralt Boix, A., Molina Pons, M.P., Borrás Llopis, M., Beltran Martínez, M.C. and González Martínez, C. (2017), Quality of goat's milk cheese as affected by coating with edible chitosan-essential oil films. Int J Dairy Technol, 70: 68-76. https://doi.org/10.1111/1471-0307.12306
Semi-hard cheese (Minas Padrão)	Zein	Xanthan gum	Unspecified microorganisms	Yes	Brazil	It works but they suggest further research.	Carolina Pena-Serna, Ana Lúcia Barretto Penna, José Francisco Lopes Filho, Zein-based blend coatings: Impact on the quality of a model cheese of short ripening period, Journal of Food Engineering, Volume 171, 2016, Pages 208-213, ISSN 0260-8774, https://doi.org/10.1016/j.jfoodeng.2015.10.039.
Semi-hard cheese (kashar)	Whey protein isolate/alginate	Ginger essential oil	*E. coli* O157:H7, *S. aureus*	Yes	Turkey	It works but they don't say if it is ready or if they suggest further investigation.	Nazan Kavas, Gökhan Kavas & Derya Saygili (2016) Use of ginger essential oil-fortified edible coatings in Kashar cheese and its effects on Escherichia coli O157:H7 and Staphylococcus aureus, CyTA - Journal of Food, 14:2, 317-323, DOI: 10.1080/19476337.2015.1109001
Cream cheese	Edible coating of chicory starch	Garlic oil /Oregano oil	*B. cereus, E. coli, L. monocytogenes, S. typhimurium,* and *S. aureus*	Yes	Colombia	Protects the food in the package in addition to having the antimicrobial agent and the bioactive packaging film, it has the coating so that the cheese does not lose moisture or fat, the results are very good with respect to the inhibition of microorganisms and prolongation of shelf life.	Molina-Hernández, J. B., Echeverri-Castro, A., Martínez-Correa, H. A., & Andrade-Mahecha, M. M. (2020). Edible coating based on achira starch containing garlic/oregano oils to extend the shelf life of double cream cheese. Revista Facultad Nacional de Agronomia Medellin, 73(1), 9099–9108. https://doi.org/10.15446/RFNAM.V73N1.75234
Semi-hard cheese (Bod Ljong)	Chitosan/water chestnut starch	Cornus officinalis fruit extract/pine needle essential oil/pine needle essential oil/nisin	*Enterobacteriaceae, Pseudomonas spp.*	Yes	China	It works but they don't say if it is ready or if they suggest further investigation.	JUN MEI, QIZHEN GUO, YAN WU, YUNFEI LI; Evaluation of Chitosan-Starch–Based Edible Coating To Improve the Shelf Life of Bod Ljong Cheese. J Food Prot 1 July 2015; 78 (7): 1327–1334. doi: https://doi.org/10.4315/0362-028X.JFP-14-402
Semi-hard cheese (kashar)	Chitosan/Serum protein	Chitosan	Molds and microorganisms	Yes	Turkey	Not yet on the market but ready.	Yangılar F. (2015). Chitosan/whey Protein (CWP) Edible Films Efficiency for Controlling Mould Growth and on Microbiological, Chemical and Sensory Properties During Storage of Göbek Kashar Cheese. Korean journal for food science of animal resources, 35(2), 216–224. https://doi.org/10.5851/kosfa.2015.35.2.216
Soft cheese (Lor)	Whey protein isolate	Peppermint essential oil	Pathogenic microorganisms	Yes	Turkey	It works but they don't say if it is ready or if they suggest further investigation.	Kavas, G., & Kavas, N. (2014). The effects of mint (Mentha spicata) essential oil fortified edible films on the physical, chemical and microbiological characteristics of lor cheese. Journal of Food, Agriculture and Environment, 12(3-4), 40-45.
Semi- soft fresh cheese (Mozzarella)	Sodium alginic acid	Potassium sorbate	*Pseudomonas spp., Enterobacteriaceae*	Yes	Italy	Does not work well.	A. Lucera, M. Mastromatteo, A. Conte, A.V. Zambrini, M. Faccia, M.A. Del Nobile, Effect of active coating on microbiological and sensory properties of fresh mozzarella cheese, Food Packaging and Shelf Life, Volume 1, Issue 1, 2014, Pages 25-29, ISSN 2214-2894, https://doi.org/10.1016/j.fpsl.2013.10.002.
Mozzarella	Alginato de sodio	Potassium sorbate	Molds and spoilage microorganisms	Yes	Italy	Not yet on the market but ready.	Marianna Mastromatteo, Amalia Conte, Michele Faccia, Matteo Alessandro Del Nobile, Angelo Vittorio Zambrini, Combined effect of active coating and modified atmosphere packaging on prolonging the shelf life of low-moisture Mozzarella cheese, Journal of Dairy Science, Volume 97, Issue 1, 2014, Pages 36-45, ISSN 0022-0302, https://doi.org/10.3168/jds.2013-6999.
Hard cheese	Mung bean starch/water chestnut starch/chitosan	Perilla oil	Bacteria and fungi	Yes	China	Not yet on the market but ready	Jun Mei, Yilin Yuan, Yan Wu, Yunfei Li, Characterization of edible starch–chitosan film and its application in the storage of Mongolian cheese, International Journal of Biological Macromolecules, Volume 57, 2013, Pages 17-21, ISSN 0141-8130, https://doi.org/10.1016/j.ijbiomac.2013.03.003.
Semi-hard cheese	Whey protein isolates	Quitooligosaccharides/lactic acid	Bacterias grampositivas y gramnegativas	Yes	Portugal	Not yet on the market but ready.	Óscar L. Ramos, Arménia C. Santos, Mariana V. Leão, Joana O. Pereira, Sara I. Silva, João C. Fernandes, M. Isabel Franco, Manuela E. Pintado, F. Xavier Malcata, Antimicrobial activity of edible coatings prepared from whey protein isolate and formulated with various antimicrobial agents, International Dairy Journal, Volume 25, Issue 2, 2012, Pages 132-141, ISSN 0958-6946, https://doi.org/10.1016/j.idairyj.2012.02.008.
White cheese	3% gliadin cinnamaldehyde films	Coating	fungi. *P. expansum* and *A. niger*	Yes	Iran, Malasia	It is a natural coating, it is ready, but it has not been applied industrially.	Shima Jafarzadeh, Seid Mahdi Jafari, Ali Salehabadi, Abdorreza Mohammadi Nafchi, U. Seeta Uthaya Kumar, H.P.S. Abdul Khalil, Biodegradable green packaging with antimicrobial functions based on the bioactive compounds from tropical plants and their by-products, Trends in Food Science & Technology, Volume 100, 2020, Pages 262-277, ISSN 0924-2244, https://doi.org/10.1016/j.tifs.2020.04.017.
Soft white cheese with skimmed buffalo or cow's milk	Liposomal chitosan	Thyme crude oil	*E. coli, L. monocytogenes, y S. aureus*	Yes	Germany	Ready to go to market, results show extended shelf life of 2-4 weeks.	Marwa Al-Moghazy, Hoda S. El-sayed, Heba H. Salama, Ahmed A. Nada, Edible packaging coating of encapsulated thyme essential oil in liposomal chitosan emulsions to improve the shelf life of Karish cheese, Food Bioscience, Volume 43, 2021, 101230, ISSN 2212-4292, https://doi.org/10.1016/j.fbio.2021.101230.
Ricotta cheese	Biodegradable film based on fish gelatin	(Seeds) Lepidium sativum Extract	*E. Coli, S. typhimurium, B.s cereus y M. luteus*	Yes	Tunicia, France	He has all the studies but has not gone to the market.	Ali Salem, Mourad Jridi, Ola Abdelhedi, Nahed Fakhfakh, Moncef Nasri, Frederic Debeaufort, Nacim Zouari, Development and characterization of fish gelatin-based biodegradable film enriched with Lepidium sativum extract as active packaging for cheese preservation, Heliyon, Volume 7, Issue 10, 2021, e08099, ISSN 2405-8440, https://doi.org/10.1016/j.heliyon.2021.e08099.
Low fat cheese - edible coating	Sodium alginate/ mandarin fiber	Oregano essential oil	*S. aureus*, psychrophilic bacteria, molds, yeasts, molds, yeasts	Yes	China	It works, it has not been marketed.	María Artiga-Artigas, Alejandra Acevedo-Fani, Olga Martín-Belloso, Improving the shelf life of low-fat cut cheese using nanoemulsion-based edible coatings containing oregano essential oil and mandarin fiber, Food Control, Volume 76, 2017, Pages 1-12, ISSN 0956-7135, https://doi.org/10.1016/j.foodcont.2017.01.001.
Any food	Starch, chitosan and pluronic	Chitosan	Unspecified	Yes	Mexico	It does not have the evidence of inhibition against microorganisms but taking into account that chitosan is antimicrobial, it could be searched against microorganisms as well as the synthetic compound used as pluronic, but it is a biodegradable material that can be used for food.	Abril Fonseca-García, Enrique Javier Jiménez-Regalado, Rocio Yaneli Aguirre-Loredo, Preparation of a novel biodegradable packaging film based on corn starch-chitosan and poloxamers, Carbohydrate Polymers, Volume 251, 2021, 117009, ISSN 0144-8617, https://doi.org/10.1016/j.carbpol.2020.117009. (https://www.sciencedirect.com/science/article/pii/S0144861720311826)

2. Resultado final matriz de decisión materiales y recubrimientos

Material	Microbial control	Sensory evaluation	Statistical analysis	Appearance of the package	Mechanical properties	Ability to survive the breakage of the cold chain	TOTAL
Weight	5	6	2	3	4	1	
1	5	3	5	4,5	5	5	91,5
2	5	0	5	2,5	3	5	59,5
9	5	0	5	5	5	5	75
10	5	5	5	0	5	0	85
13	5	5	5	0	4	1	82
14	3	0	5	4	0	0	37
15	5	5	5	5	0	5	85
16	5	5	5	5	0	0	80
17	3,5	5	5	0	0	1	58,5
25	5	0	5	0	0	0	35
26	5	3,5	5	0	0	3,5	59,5
27	4	3,5	5	3	2	0	68
30	5	0	2	0	0	0	29
31	5	0	5	3	5	0	64

Material	Microbial control	Sensory evaluation	Statistical analysis	Ability to survive the breakage of the cold chain	TOTAL
Weight	3	4	2	1	
19	4	5	5	0	42
21	4	0	5	0	22
22	5	5	5	0	45
18	5	5	5	0	45