SEVEN publicações acadêmicas

Nanotechnology applied to packaging production: Review

Crossref doi
https://doi.org/10.56238/Connexpemultidisdevolpfut-061

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ABSTRACT
In view of the search for intelligent and sustainable packaging, this research aimed to understand how nanotechnology can be used in favor of the production of primary packaging. From the comprehension of the literature on the subject, it was discussed in a qualitative way about the differences between the traditional primary packaging compared to the technological ones and what were the main nanotechnological advances in packaging in recent years. The potential security problems and current legislation were also evaluated, discussing the current scenario and the future perspective in the interim. It could be concluded from the data collected that nanotechnology applied to the production of primary packaging has the potential to bring significant benefits in several areas, such as protection against external agents, sustainability and logistics optimization. However, it is essential to ensure the safety of materials and regulate their use responsibly and, for this, research and development in this area are necessary to overcome the challenges to then start producing nanotechnological packaging on a large scale.

Keywords: Nanotechnology, Packaging, Nanomaterials, Smart packaging, Technological advancement.

1 INTRODUCTION

The preservation of food and products in general depends on the quality of the packaging. Proper packaging helps to avoid waste, extend the shelf life of products and ensure that they reach the final consumer in an ideal state for use (JAGTIANI, 2021).

Each type of packaging has its own characteristics and uses. While some are better for fresh foods, others are ideal for processed or processed foods. The choice of packaging may also depend on the requirements of the product, such as protection against light, air, humidity and temperature. SIDDIQUI *et al* (2021) also state that to keep products free of contaminants, packaging is crucial, especially for food, as consumers may face health risks due to contamination. Packaging can (and should) be designed and produced in such a way as to prevent microorganisms from coming into contact with food, keeping them safe for consumption.

Packaging also plays an important role in preserving the cleanliness of products in general. For example, packaging of personal care products can keep products clean and safe for use by avoiding cross-contamination between various other products. On the other hand, the packaging of cleaning products can prevent products from leaking, which can cause damage to other surfaces or products, as well as damage to humans (ABRE, 2022).

The food and pharmaceutical industry is increasingly adapting active and intelligent packaging as an inventive solution to extend the shelf life of products and simplify production processes. Still, this type of packaging facilitates distribution logistics, reducing the need for preservatives in food formulations, allowing the limited application of packaging in food and improving the quality, variety and *marketing characteristics*, in addition to providing essential information for the safety of (JANJARASSKUL; SUPPAKUL, 2017).

In addition to being essential to preserve food and other products, avoiding waste and protecting consumers from contamination, packaging keeps products clean and free from contact with the external environment, keeping them safe for use. In the meantime, nanotechnology has proven to be one of the most promising areas for the development of new materials and products with innovative properties, which allows it to be used also in the packaging sector (PETERS *et al*, 2014). This research raised data from the literature that allowed us to examine the possibilities of using nanotechnology in the manufacture of packaging.

2 LITERATURE REVIEW

2.1 NANOTECHNOLOGY: DEFINITION AND FUNDAMENTAL ASPECTS

Nanotechnology is a very inventive area of science that allows materials to behave in ways that have never been seen before. It is seen as a general-purpose, cross-functional technology that allows a technology to be incorporated and used in multiple products, processes, or systems.

Nanotechnology can be defined by applying the physical properties of atomic molecules with measurements between 0.1 and 1000 nm. The "nano", from which this field derives its name, is a prefix denoting 10-9 and comes from *nanos*, a Greek word meaning "dwarf". In the case of nanotechnology the prefix refers to things about a billionth of a meter in size, but other prefixes can be applied to any unit of the *International System of Units* (SI) to present multiples of a given unit (ROGERS; ADAMS; Pennathur, 2014). According to Mlinar (2015), who presents a review on the inverse approach in the design of materials at nano and macro scale, microtechnology focuses on materials and devices at the micrometric scale, which is 10-4 meters, while macrotechnology focuses on objects of macroscopic size; that is, larger than 1 meter. The main difference between the three is in the dimensions of the manipulated objects and their properties. The term macroscale refers to objects, processes, or systems larger than a few millimeters in size. Perovic *et al* (2018) state that although there is no precise and consensual definition for the macroscale, most people consider that the macroscale starts around 1 mm in size, varying according to the context in which it is used.

The manipulation of materials at nanometric and micrometric scales is the focus of nanotechnology and microtechnology studies, respectively. Although these areas have much in common, there are some significant differences in their building principles (SHEREMET *et al*, 2019).

In nanotechnology, the most common method of building structures is "*bottom-up*," which consists of structures made from smaller components and blocks, such as atoms and molecules. Yang and Fang (2017) state that this method is commonly used in the synthesis of nanomaterials such as nanowires and carbon nanotubes, which are created by self-organization of atoms and molecules. Using tools such as atomic force microscopes (AFM) and scanning electron microscopes (SEM) one can also perform direct manipulation of atoms and molecules in the *bottom-up construction.* On the other hand, in microtechnology, the most common approach to building structures is "*top-down*," in which structures are built from larger materials that are gradually reduced in size down to the micrometer scale. This approach is commonly used in the manufacture of microelectronic devices, such as computer chips and sensors, built through the selective removal of layers of materials using lithography techniques (NOWAKOWSKI *et al*, 2016).

Although the *bottom-up* approach in nanotechnology allows the construction of highly precise structures at the nanometer scale, it can be limited by the complexity and cost of material synthesis processes. The *top-down* approach of microtechnology allows the construction of more complex structures from existing materials, but may face limitations in accuracy and the ability to build structures at the nanometer scale (SHEREMET *et al*, 2019).

2.2 BIRTH AND DEVELOPMENT OF NANOTECHNOLOGY

According to Schulz (2013), nanotechnology is believed to have emerged in 1959, when the renowned American physicist Richard Feynman (1918–1988), would have uttered in a lecture the following sentence: "There is a lot of space down there", alluding to the difficulty of manipulating and controlling things at the atomic scale and emphasizing that there was much to be discovered about particles and systems at the nanometer scale. He believed that just as there is vast space to explore abroad, there was also potential in the quest for the manipulation and control of matter on very small scales, and in this lecture Feynman discussed the possibility of manipulating atoms and molecules individually and how this would promote significant advances in several areas, thus paving the way for the development of nanotechnology.

The term nanotechnology was coined fifteen years later, in 1974, by Japanese researcher Norio Taniguchi (1912-1999). The engineer Eric Drexler, author *of the book "Engines of creation: the coming era* of nanotechnology" and considered the "father" in the field of nanotechnology, was fundamental for the diffusion of this area of science and for the technological advances at the time, such as molecules with large chains of carbon atoms and the creation of microscopes that made possible the manipulation of individual atoms (SCHULZ, 2013).

Nanotechnology has emerged with the need to create lighter and stronger materials, smaller and more efficient electronic devices and systems with specific properties and functionalities that are not found in conventional materials. These properties can include high mechanical strength, higher electrical conductivity, greater energy efficiency, increased energy storage capacity, better drug transport capacity, new forms of energy, and much more being recognized as one of the top three technologies supporting the development of science, technology, and economics in the world (DU; LAUGH; PAK, 2021). According to Du, Ri and Pak (2021), this field focuses on the study and development of materials and systems at a nanometer scale, with the aim of creating new materials and devices with unique properties and functionalities. Some of the major advances and developments of nanotechnology in the world today include:

- Nanomedicine: According to Müller and Voorde (2016), a new generation of nanotechnology-based diagnostic devices, such as biosensors and nanorobots, is being developed that can detect diseases more accurately and early such as tissue- and organ-induced growth, cancer, cardiovascular and cerebrovascular diseases, and other slow-release and controlled, difficult-to-target drug therapies.

- Energy: In the energy field, nanotechnology can provide key technologies in new, clean, efficient and alternative energy sources. For example, lithium-ion batteries with graphene nanoparticles are being developed to increase battery life and reduce charging time. In addition, nanotechnology solar cells are being developed to increase energy conversion efficiency and reduce production cost (MOCHANE *et al*, 2018).

- Electronics: According to Islam *et al* (2015), nanotechnology has been widely used in the area of electronics, mainly in the search for materials with greater efficiency and lower energy consumption, as well as being used to create more advanced and smaller electronic materials and devices. For example, nanotube transistors have potential advantages in use in transistor technology, including high electron mobility, high thermal conductivity, and mechanical flexibility. These properties make carbon nanotubes promising candidates for use in flexible and wearable electronics, and are used to create faster, more energy-efficient processors present in high-performance computing applications. In addition, flexible and high-resolution nanotechnology-based screens are being developed for electronic devices such as *smartphones* and *tablets* (ISLAM *et al*, 2015).

- Materials: Nanotechnology is being used to create stronger, lighter, more corrosion-resistant materials with high thermal and electrical conductivity; composite materials reinforced with carbon nanotubes are being used in the aerospace industry to reduce the weight and increase the strength of aircraft, which assists in reducing fuel consumption and greenhouse gas emissions. In addition, nanotechnology coatings are being used to create more durable and scratch-resistant materials (SKOCZYLAS; SAMBORSKI; KLONICA, 2019).

- Environment: In the field of environmental protection, according to Iqbal, Preece and Mendes (2012), nanotechnology can be used to control water, air and soil pollution, being used to create more efficient and sustainable environmental solutions, offering new opportunities for the circular economy and sustainability through the development of more durable nanostructured materials. Thus, it is possible to improve energy efficiency, reduce energy consumption and increase the useful life of systems, which results in greater savings of resources and reduction of waste generated, among other possibilities

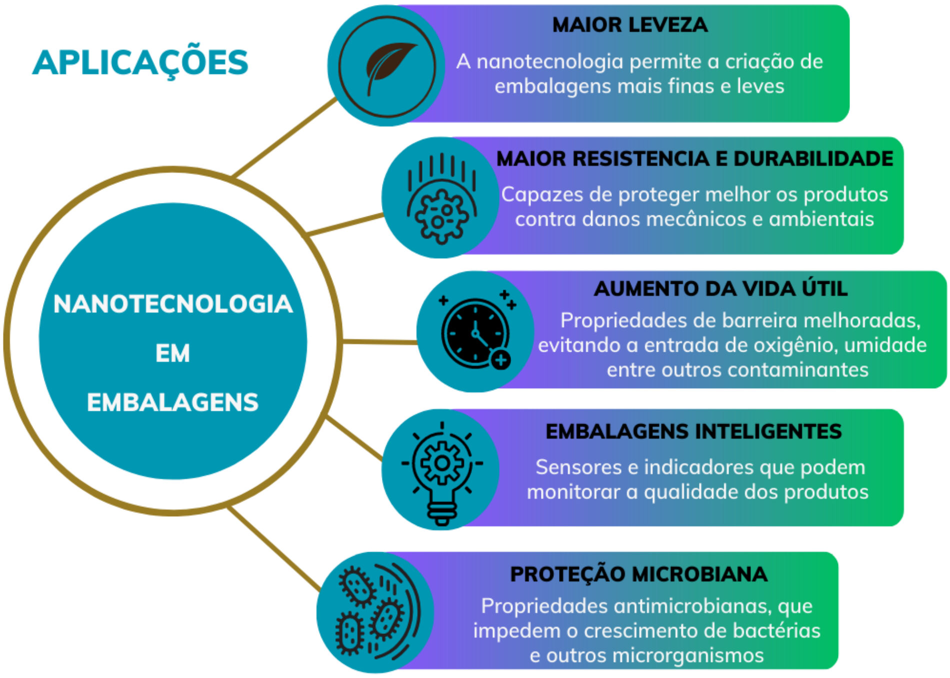
2.3 PACKAGING AND NANOTECHNOLOGY

According to the Resolution of the Collegiate Board (RDC) 259/2002, packaging is defined as "container, package or packaging intended to ensure the conservation and facilitate the transport and handling of food." (BRAZIL, 2002). They are produced and selected according to the materials that are composed to meet their primary function of protecting the product from adverse environmental conditions such as moisture, microbial contamination, oxygen, sunlight and physical hazards, which are the shock, impact, compression, vibration and perforation that can occur during storage and transport (TESCAROLLO; DICK; OLIVEIRA, 2020).

Nanotechnology has been a valuable tool in the search for safer and more efficient packaging. The use of nanoparticles in packaging materials can bring benefits such as improving the barrier against gases and vapors, increasing mechanical resistance and reducing light permeability, as well as enabling the controlled release of substances such as preservatives and antioxidants (NATHALIE *et al*, 2017). For example, the use of nano-CaCO3 (CC) as an agent incorporated into polymers where nano-CC have considerable mechanical and barrier properties. The addition of nano-CC in the polymer matrix can significantly improve the mechanical strength and barrier against gases and vapors, increasing the shelf life of food and pharmaceutical products (SETHY *et al*, 2019).

Another example of high-tech packaging is the processing and packaging of food using nanostructured components. These nanoparticles can be used in food processing as antimicrobials, nutrient transporters, and food additives, as well as can be used as fillers in food packaging, increasing strength, mechanical efficiency, and material quality (YU *et al*, 2018). Nano sensing, in turn, acts on issues of quality monitoring and safety assessment with the use of nanotechnology (SIDDIQUI *et al*, 2021). Figure 1 presents a summary of the applications of nanotechnology in packaging.

Figure 1: Applications of nanotechnology in packaging



Source: Prepared by the Authors, 2023.

According to Singh *et al* (2023), nanotechnology can facilitate the process of creating biodegradable packaging and significantly improve its properties such as thermal and mechanical resistance, the barrier against gases and humidity, transparency and the ability to extend the shelf life of food, as already explained. Nanotechnology also allows the creation of biodegradable and compostable packaging, which degrades more easily in the environment by reducing the amount of waste (PETERS *et al*, 2014).

One of the most common applications of nanotechnology in packaging is the incorporation of nanoparticles into materials such as polymers, paper and metal. These nanoparticles can be used to improve the strength and durability of packaging; in addition, nanostructured coatings can be applied to a variety of materials, as well as to confer barrier properties against gases and moisture (JAGTIANI, 2021). According to Ongaratto, Vital and Prado (2022), this technique can be used to produce more effective and sustainable packaging, with the potential to be used on a large scale in industrial applications.

2.4 NANOTECHNOLOGY APPLIED TO FOOD PRESERVATION

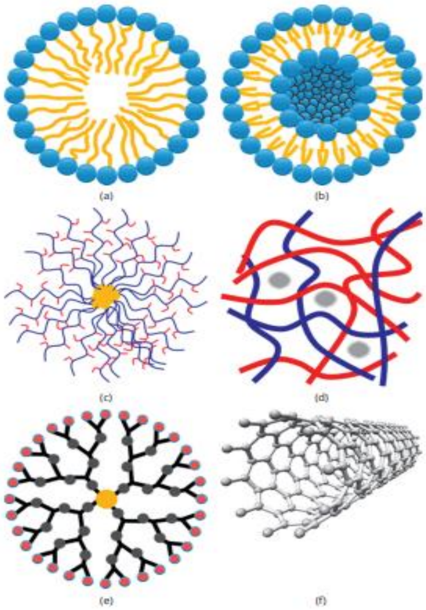
One of the advantages of using nanotechnology in food preservation through antimicrobial and antioxidant packaging is that they have the attribute of reducing dependence on chemical preservatives, which is beneficial for both human health and the environment (ONGARATTO; VITAL; PRADO, 2022).

Food preservation can be improved at various points by nanotechnology, from the application of antimicrobial nanoparticles in food packaging to the development of smart sensors and the use of lipid nanoparticles in the encapsulation of bioactive compounds. However, it is essential to ensure that these technologies become safe and efficient before their widespread deployment in the food industry (SINGH *et al*, 2023).

2.4.1 Applications of organic nanomaterials in food preservation

The nanocarriers (Figure 2) used in organic-based applications are made of polymeric nanoparticles or lipid-based nanoparticles, such as liposomes, micelles, dendrimers, nanoemulsions, hydrogels, and carbon nanotubes (YU *et al*, 2018).

Figure *2*: Representation of 6 types of nanocarriers: (a) Micelle*;* (b) Liposome*;* (c) polymeric nanoparticle*;* (d) hydrogel nanoparticle*;* (e) Dendrimer*;* (f) Carbon nanotube.



Source: Yu *et al*, 2018.

Lipid-based nanomaterials are organic nanomaterials with high utilization, since they can be manufactured on an industrial scale from natural components and have the ability to encapsulate compounds with various solutions. A promising application of nanotechnology in food preservation is the use of lipid nanoparticles to encapsulate bioactive compounds such as vitamins and antioxidants, so these nanoparticles can be added directly to food, helping to improve nutritional quality and increase the shelf life of food. They are present in food processes such as juices, dairy and soft drinks (JUNGES *et al*, 2022).

During the food processing phase, physical, synthetic and natural changes can be recorded with the help of nanosensors integrated into the packaging. The intention is that smart packaging can detect toxic substances and synthetic combinations, for this, optical immunosensors based on thin films and carbon nanotubes are able to perform the recognition of various microorganisms and harmful substances in food, and because they are suitable in terms of costs is an attractive application in the field of nanotechnology in food (THEKKETHIL *et al*, 2019).

2.4.2 Applications of inorganic nanomaterials in food preservation

When it comes to inorganic nanomaterials, metallic elements such as silver, magnesium, iron and dioxides such as titanium, as well as non-metallic elements such as silicates and selenium are present in several applications (PETERS *et al*, 2014). One of the focuses of applications of nanotechnology in food preservation is the use of nanosilver, which is the best known and commonly used, due to the remarkable characteristics and toxicity it has against various microorganisms. These nanoparticles can be added to food packaging to prevent microorganisms from developing, embedded in various carriers or forming nanocomposites with polymers, originating active packaging that acts as a barrier and protection for meats, fruits and vegetables from bacteria and fungi (NATHALIE *et al*, 2017; BAHRAMI *et al*, 2020). Still, nanosilvers have other properties, such as high thermal stability, catalytic activity and optical behavior. Therefore, they can be used as an antimicrobial coating (Figure 3) in food packaging made of polypropylene (EGODAGE *et al*, 2017).

Figure 3: Antibacterial mechanisms of silver nanoparticles

Source: S3Nano, 2022

However, the consumption of food in contact with nanopackaging can present a significant health risk due to the transfer of particulate nanomaterials from packaging to food as a result of poor packaging performance. Some studies have found that packaging material containing silver nanoparticles can migrate into food and be ingested by humans, however, the idea about the toxicity of this intake is limited, but there is a possibility of it accumulating in different organs, such as kidneys, stomach, small intestine, liver and spleen in animals (SAHOO *et al*, 2020).

2.5 SMART PACKAGING

According to Cushen and Cummins (2016), the increasing global population is putting pressure on food resources so as to raise the price of *commodities*, which also has its value impacted with the increase in food waste.

In the food sector, researchers with the *marketing* department have developed a way to communicate the quality and safety of food through the bar code, making use of paints that change color when coming into contact with a microorganism, for example. The composition of the paint is based on the application of interest, and the compound used must be sensitive to what you want to identify as unusual, so the barcode will change color and the consumer and / or merchant will know that that product is unsuitable for consumption and use (PASCALL, 2018). Some examples of smart packaging with potential to be explored are the antioxidant and antimicrobial packaging, mentioned earlier, in addition to those that have indicators of time, temperature, shelf life, ethylene controllers for fruit and vegetable packaging, and control of color, humidity and odor reduction that can be widely studied to pack meats. As smart packaging is introduced to the market, the trend is for consumers to become increasingly dependent on them and start aiming for all to be standardized in this way (PASCALL, 2018). Figure 4 represents the categorization of smart packaging and its active agents.

Figure 4: Categories of smart food packaging and its active agents

Source: Adapted from Vilela *et al*, 2018.

2.6 NANOTECHNOLOGICAL AND SUSTAINABLE PACKAGING

According to Sahoo *et al* (2020), smart packaging using antigen-specific biomarkers and nanoparticle amalgamation to create nanocomposite polymer films are being developed and, on this topic, a long research can be carried out to expand industrial applications in the future. The nanocomposites, for example, are incorporated into the polymeric matrix of the substances because they contain an extensive surface area in order to favor the interactions of the charge matrix and its performance, allowing the impermeability to gases and consequently the conservation of the food (KUMAR; SADHU; Singh, 2018).

The use of nanosensors in film packaging has a great potential to be explored in order to detect gases released in food spoilage, since these sensors are able to identify spoilage at all stages of the food chain, consequently reducing total food loss and benefiting producers, retailers and consumers (SAHOO *et al*, 2020). Enzymes embedded with gold nanoparticles are also used to identify microbes and detect gases related to food products such as perilene-based fluorophore nanofibrils that are able to point out the spoilage of fish and meat by detecting gaseous amines. Nanobarcodes have also been used for identification and safety in packaging and, in this way, the use of smart sensors has been shown to be beneficial both for consumers in terms of ensuring the quality of products, and for producers in relation to the rapid distribution and authentication of goods (KUMAR; SADHU; Singh, 2018).

With regard to the production of sustainable packaging, nanocomposites are carbon-neutral biodegradable molecules that have potential for use in the very near future (SAHOO *et al*, 2020). In addition, several bioactive organic compounds have demonstrated that they can provide properties for food packaging materials and that they can be incorporated into biopolymer matrices, and to develop sustainable antimicrobial packaging systems, one should consider the end of life of packaging (YILDIRIM; RÖCKER, 2021). With regard to environmental impact, Yildirim and Röcker (2021) argue that the next generation of packaging production will inevitably aim at replacing petroleum-derived plastics with biodegradable materials from biological and renewable resources.

3 METHODOLOGY

This research was carried out with the methodological basis of bibliographic research, in a descriptive way, in which it aims to collect information and elaborate a review on nanotechnology applied to the production of packaging. The methodological procedure of the present work can be classified according to Gil (2002) as a research of an exploratory nature, whose fundamental purpose is to categorize, understand and perform the leveling of theories and facts about the discoveries in the field of nanotechnology and its application in packaging.

For the elaboration of this research we used the foundations of a theoretical review of the literature from the analysis of scientific articles, monographs, dissertations, theses and books through the following databases and search sites: IEEE Xplore, Wiley Online Library, Springer, ACS Publications, Science Direct, Scielo, and Google Academic, focusing on publications of recent years and fundamental sources for the theoretical basis in publications of the last decades. All the cited material was previously selected based on scientific articles classified according to Qualis in B2 or higher, for greater reliability of the information present in the theoretical framework.

4 RESULTS AND DISCUSSIONS

From the bibliographic survey, it was possible to elaborate Chart 1, which illustrates a comparison between the main advantages and disadvantages of each type of packaging.

Frame 1: Comparison between traditional and technological packaging

Traditional		Technological	
Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Low production cost	Durability	Extending the shelf life of products	High cost of production
Practicality	Traceability	Reduction of materials and waste	Complex production
High availability and variety	Preservation of product quality	Sustainability and waste reduction	Additional regulations
Consumer Acceptance	Environmental impact	Real-time information	Difficulty familiarizing

Source: Prepared by the authors, 2023

With the promising advance of technological packaging in search of mitigating the disadvantages of traditional packaging, nanotechnology began to be inserted in the production of packaging through scientific development to achieve market expectations, both those related to the optimization of the logistics sector, as well as those involving consumer health and environmental conservation. The way to achieve these objectives involved technological advances that were cited by the authors, as indicated in Chart 2.

Frame 2: Technological advances in the production of nanopackaging

Authors, year	Reference	Technological advancement cited
JAGTIANI, 2021	Artigo de revista: *"Advancements in nanotechnology for food science and industry"*	- Incorporation of nanoparticles in materials such as polymers, paper and metal to improve the strength and durability of packaging; - Combination of polymers with organic and inorganic nanoelements to obtain more resistant, durable, affordable and economically viable packaging; - Production of biodegradable nanocomposites for food packaging.
SIDDQUI *et al, 2021*	Artigo de revista: "*Nanomaterials in Smart Packaging Applications: a review*"	- Materials consisting of nanoparticles of metallic oxides of iridium and ruthenium doped with titanium, tantalum and silver, with dye such as methylene blue to indicate changes in oxygen, pH, time and temperature; - Nano sensing in packaging for quality monitoring and safety assessment.
SAHOO *et al, 2020*	Artigo de revista: "*Nanotechnology: current applications and future scope in food"*	- Smart packaging using antigen-specific biomarkers and nanoparticle amalgamation to create nanocomposite polymer films; - Sustainable packaging with nanocomposites: carbon-neutral biodegradable molecules.
SETHY *et al, 2019*	Artigo de revista: *"Nano-CaCO3-embodied polyacrylicacid/dextran nanocomposites for packaging applications"*	Application of nano-CC in the polymer matrix to significantly improve the mechanical strength and the barrier against gases and vapors, increasing the shelf life of food and pharmaceutical products.
THEKKETHIL *et al, 2019*	Trabalho em congresso: *"The Role of Nanotechnology in Food Safety: a review"*	Nanosensors integrated into the packaging using carbon nanotubes to identify microorganisms and harmful substances in food.
KUMAR; SADHU; SINGH, 2018	Book article: "*Nanotechnology: key for sustainable future*"	- Nanocomposites incorporated into the polymeric matrix of substances because they contain an extensive surface area in order to favor the interactions of the charge matrix and its performance; - Enzymes embedded with gold nanoparticles to identify microbes and detect food-related gases: perilene-based fluorophore nanofibrils - Nanobarcodes for identification and safety in packaging.
YU *et al, 2018*	Artigo de revista: *"An Overview of Nanotechnology in Food Science: preparative methods, practical applications, and safety"*	Use of nanoparticles in food packaging fillers, increasing strength, mechanical efficiency and material quality.
EGODAGE *et al, 2017*	Trabalho em congresso: "*"Novel antimicrobial nano coated polypropylene based materials for food packaging systems"*"	- Nanoparticles with antimicrobial characteristics to incorporate antioxidant properties, which can extend the shelf life of packaged products and reduce food waste;

		- Use of nanosilvers to reinforce the packaging with high thermal stability, catalytic activity and optical behavior.
Nathalie *et al, 2017*	Artigo de livro: "*Nanotechnologies for Active and Intelligent Food Packaging: opportunities and risks*"	Use of nanosilver embedded in various carriers to prevent microorganisms from developing, or forming nanocomposites with polymers, giving rise to active packaging that acts as a barrier and protection for meats, fruits and vegetables from bacteria and fungi.
PETERS *et al, 2014*	Artigo de revista: "*Inventory of Nanotechnology applications in the agricultural, feed and food sector*"	Use of clays composed of montmorillonite or bentonite, obtained from volcanic rocks, whose nanoscale layer structure is modified to combine the polymer matrices of various types of packaging.

Source: Prepared by the authors, 2023.

The bibliographic survey carried out indicated that in the field of packaging production, nanotechnology is mostly explored for application in food packaging, indicating that there is potential in the advancement of science to promote nanotechnological food packaging with food efficiency and safety with a focus on solving the problems of traditional packaging regarding food spoilage, in addition to benefiting the logistics chain. There have been notable advances on the applications of nanotechnology in the science and research of food packaging, such as the detection of toxins, pathogens and pesticides, as well as the tracking and monitoring that allow to ensure the maintenance of food quality. It is known that the availability of trained labor, as well as the acquisition of state-of-the-art technical equipment are not obstacles in this aspect, however, some nanosystems and/or nanocomponents are still in the initial stage of development and, therefore, it is necessary that more extensive and in-depth research be carried out to start a broad production.

Simultaneously, challenges related to the health and safety of consumers, as well as the possible impacts on the environment, are taken into account in order to pressure the regulatory bodies so that the rules and legislations are established to delimit the production of reliable nano packaging through ecologically correct and economically viable solutions, simplifying the production method to achieve the optimal cost-benefit. This is a delicate factor that requires attention because, for nanotechnological packaging to have a high acceptance rate, it is necessary that the cost of these, added to the cost of the products they pack, do not result in values above the market average in order to induce the consumer to opt for more economical traditional packaging. In addition, the proposed solution should ensure that nanomaterials used in packaging do not migrate into food and consumers are not exposed to risks of intoxication.

In short, the application of nanotechnology in the production of primary packaging currently presents challenges related to economic and productive viability, in addition to discussions on the safety of nanotechnological materials and government regulation. Sahoo et al (2020) state that overcoming these obstacles is in line with predictions that indicate that nanotechnology will advance with growth rate until 2050 to solve most industrial and social problems due to its ability to find friendly solutions at both the micro and macro levels.

5 CONCLUSION

From the bibliographic survey on nanotechnology combined with the review of the main types of packaging used in everyday life, it is concluded that the fusion of these two subjects tends to bring benefits to various areas and to the world population in general with regard to protection against external agents, sustainability and logistics optimization. This is due to the fact that it is not yet completely safe to produce nano packaging on a large scale, especially when it comes to primary packaging that is in direct contact with the products and, therefore, still pose aggravating risks to the health of humans when they are produced with nanomaterials. The expectation is that this barrier will be overcome when there are regulations that safeguard the use of nanotechnology in the production of packaging and, subsequently, this regularization will influence the production process, simplifying it as these packages are increasingly introduced into the market, aiming to make consumers dependent.

In the long term, it is expected that with the reduction in the productive complexity of nanotechnological packaging, balancing production costs and the implementation of regulatory standards, the standardization of these packages will be desired by the economic market and by the largest share of consumers, and the industry should exert a power of influence by the small portion that will have difficulties in familiarizing and adapting to this new model.

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