Applications of nanotechnology in smart food packaging

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ABSTRACT
The growing demand for food has contributed to an increase in plastic waste, mainly from packaging. In 2020, only 23.1% of post-consumer plastic waste was recycled in Brazil, resulting in a significant amount of non-biodegradable waste that remains in the environment for long periods, affecting human health and the environment. Most of this waste comes from traditional petroleum-based food packaging, such as polyethylene, polypropylene and polystyrene. It is estimated that 31.9 million tons of plastic waste enter the environment every year, with a considerable portion contaminating the oceans. Despite these environmental challenges, the demand for plastics is expected to continue to grow in order to meet society's resource-efficient needs (FERREIRA et al., 2022).

Keywords: Nanotechnology, Smart packaging, Food.

INTRODUCTION

The growing demand for food has contributed to the increase in plastic waste, especially from packaging. In 2020, only 23.1% of post-consumer plastic waste was recycled in Brazil, resulting in a significant amount of non-biodegradable waste that remains in the environment for long periods, affecting human health and the environment. Most of this waste comes from traditional petroleum-based food packaging, such as polyethylene, polypropylene, and polystyrene. It is estimated that annually, 31.9 million tons of plastic waste enter the environment, with a considerable portion contaminating the oceans. Despite these environmental challenges, the demand for plastics is expected to continue to grow to meet society's resource-efficient needs (FERREIRA et al., 2022).

In this context, the role of nanotechnology emerges, considered a revolutionary technology in the production of goods and services, being widely applied in sectors such as food, pharmaceuticals, cosmetics and the chemical industry. Nanoscience and nanotechnology are the new frontiers of this century, recently applied in agriculture and food. Its applications include drug delivery, pharmaceuticals, intelligent nutrient delivery, and nutraceutical nanoencapsulation. Advanced technologies, such as DNA microarrays, microelectromechanics, and microfluidics, are unlocking the potential of nanotechnology in food (FARIA, 2019 apud SOUZA et al., 2022). These technologies have already been applied in

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electronics, communication, energy production, medicines, and industrial foods, seeking to mimic natural nanodevices (SANTOS, 2018 apud SOUZA et al., 2022).

Nanotechnology contributes significantly in all areas of the industry and has recently been highlighted in the food industry, especially within the field of packaging. It turns out that the smart packaging market is constantly growing, and innovation is crucial for companies to stand out amidst the competition. In times of competitiveness, creativity and innovation are essential to keep products on the market.

According to Schimmelfenig, Santos and Bernieri (2009, apud HOSSAKI; VOLANTE, 2018), smart packaging is crucial in today's era, connecting consumer, product and brand. For the food industry, avoiding waste, reducing costs, and ensuring the quality of its product is extremely important. The application of nanotechnology will add value, due to low manufacturing costs, an example of which is the ceramic nanoparticle that can be formed on surfaces of volumetric materials using lower temperatures than other materials, thus reducing costs (HOSSAKI, VOLANTE, 2018). Therefore, the main challenge of the food industry is the loss of quality during storage, increasing waste (BOLUMAR et al, 2014 apud ONGARATTO; VITAL; PRADO, 2022).

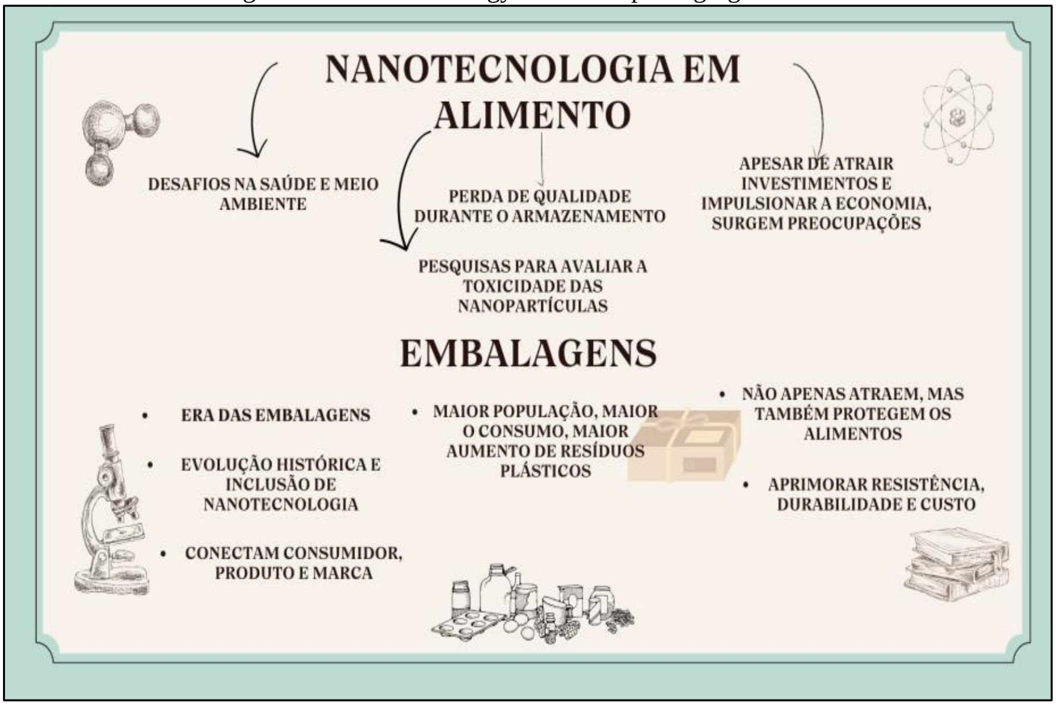
OBJECTIVE

Considering that packaging performs several functions, not only to store the product, the central objective of this study emerges, which aims to analyze the state of the art of research on smart packaging to preserve, protect, facilitate transportation, as well as interact with the consumer informing about the product and captivating him to buy it (HOSSAKI; VOLANTE, 2018).

Despite attracting investments and boosting the economy, concerns arise about possible risks to health and the environment, because as the population increases, the greater the number of consumers, consequently, plastic waste will increase (FERNANDES; OLIVEIRA, 2019). Thus, research that allows the production of smart and sustainable packaging can mitigate future risks and impacts on society and the environment. In this approach, it is necessary to advance in research in order to analyze the possibilities and limitations of this product.

Along these lines, Figure 1 illustrates the objective of this study by listing the analysis of the applications of nanotechnology in smart food packaging.

Figure 1 – Nanotechnology and smart packaging for food



Source: Prepared by the authors.

METHODOLOGY

The technological artifact that makes up this study is intelligent active packaging, a technology produced to preserve quality, extend shelf life and monitor the state of the product. According to researchers, it is the packaging of the future because it makes use of high technology and advanced techniques with the application of nanotechnology (ONGARATTO; VITAL; PRADO, 2022; DURÁN et al., 2019). This type of packaging emerges as an improvement for the main functions of a package, which are containment, protection, conservation and information. Packaging not only attracts but also protects food while maintaining its quality. Thus, the present work explores the application of nanotechnology in the development of packaging, allowing us to analyze how this technology can contribute to the durability of the food, as well as the benefits for the consumer (HOSSAKI; VOLANTE, 2018).

In order to deepen the theme of the applications of nanotechnology in the production of smart packaging for food storage, the methodology of the Systematic Review in the Literature (RSL) (CROSSAN and APAYDIN, 2010) was applied, aiming to gather a theoretical-practical substrate of research in the area. The systematic search was carried out in Capes, Scielo and Google Scholar databases, from 2018 to 2023. In addition, a random search was carried out in sources that allowed the compilation of relevant information for analysis, as described in the body of this work.

DEVELOPMENT

For Costa, Sales Júnior and Souza (2019, p. 1) "the development of new packaging technologies has been growing in order to ensure the sensory and nutritional quality of food, as well as the food safety of the consumer, as they prevent the physical, chemical and microbiological deterioration of the food".

According to the literature, it was possible to identify two types of packaging, active and smart, which, despite having different concepts, are interconnected and act together in the preservation of the product. Because they work together, a package can be active and intelligent at the same time.

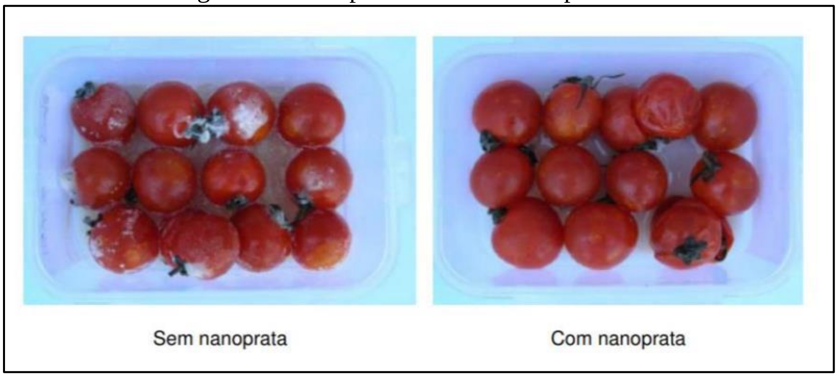
According to Ongaratto, Vital and Prado (2022, p. 2), "active packaging interacts with the product in order to provide a positive characteristic by controlling its quality, protecting and increasing the shelf life of food through the incorporation of active compounds". Thus, the use of active packaging takes place through the application of technologies for the preservation and control of the product. For the control made by the active packaging, it is important for the intelligent packaging to monitor and provide information about the condition and quality of the product.

Smart packaging is developed based on nanotechnological biosensors and is so called because it interacts with the consumer by showing the stage of ripeness of the product in the case of fruits, or spoilage in the case of meat products, through quality sensors. Some of these sensors are known as electronic tongue or nose, which show, for example, color changes when the product is unfit for consumption (ONGARATTO; PRADO VITAL, 2022). The monitoring and protection done by this type of packaging brings benefits during a large part of the product's life cycle, it starts with the preservation of the product during transport and continues with the ease of identifying products in poor condition during delivery to the seller or even sale to the consumer.

The use of nanosensors has been essential to verify the quality of the product, so it monitors everything that happens to the product from the moment it is packaged. According to Moore (2009, apud HOSSAKI; VOLANTE, 2018) the solution proposed to the food industry to identify if the packaging has been violated is the application of an intelligent oxygen ink with nanocrystalline indicators, so it would be possible to identify the presence of oxygen in the packaging. Working in conjunction with other technologies, nanosensors can identify if there is product spoilage caused by any errors during the packaging process.

According to information from the Brazilian Packaging Association (APRE, 2019), smart packaging with nanosensors helps identify gases in food that are spoiling, in order to alert consumers. According to Moore (2009 apud HOSSAKI; VOLANTE, 2018) researchers at Bayer Polymers have produced, through nanoparticle technology, plastic packaging that is more resistant to air, made of With silver and zinc nanoparticles, it has the function of discarding microorganisms that spoil the food. Both do not alter the characteristics of the food. An example is in helping to keep meats fresh and free of contamination for a longer period, as shown in Figure 2 using tomatoes.

Figure 2 - Example of a silver nanosphere



Fonte: SCHRAMM, 2012 apud HOSSAKI; VOLANTE, p. 624, 2018.

According to Embalagem Marca Magazine (2012 apud HOSSAKI; VOLANTE, 2018), a team from MIT – Massachusetts Institute of Technology in the United States, with the aim of avoiding waste in viscous food packaging, developed a non-toxic and superviscous liquid, preventing food debris from sticking to the containers. A group of engineers and nanotechnologists from the MIT named the liquid "LiquiGlide" which is a lubricating coating allowing products to glide easily. The chemical compounds used, according to the MIT engineers, are approved by the U.S. Food and Drug Administration (FDA). With this new coating, they claim that about one million tons of food could be saved from waste (HOSAAKI; VOLANTE, 2018).

To extend the shelf life of fresh meats, active and intelligent packaging is studied. Active packaging incorporates antimicrobial and antioxidant compounds, while smart packaging visually interacts with the consumer, using biosensors for traceability. Made of biopolymers and gaseous compounds, these technologies seek to preserve meat, reduce environmental impacts, and ensure food safety. However, not all research is applicable on a large scale in the industry, highlighting the importance of relevant advances (FANG et al., 2017 apud ONGARATTO; VITAL; PRADO, 2022).

Active packaging interacts with the product in order to provide a positive characteristic by controlling its quality, protecting and increasing the shelf life of food through the incorporation of active compounds (ONGARATTO, VITAL, PRADO, 2022). Thus, the use of active packaging takes place through the application of technologies for the preservation and control of the product. For the control made by the active packaging, it is important for the intelligent packaging to monitor and provide information about the condition and quality of the product.

Active and intelligent packaging has characteristics that can be highlighted, such as: control of oxygen, ethylene and moisture present in the packaging to prevent oxidation, maturation and growth of microorganisms in various types of food. Packaging with antimicrobial action containing agents that kill or inhibit microorganisms that may be present in the packaging. Indicators of temperature, freshness, ripeness, contamination that are responsible for informing the condition of the product. Use of a barcode or QR code to show information on date of manufacture, batch, origin and traceability, which are extremely important in products that require quality control (ONGARATTO; VITAL; PRADO, 2022).

While the technology used in active, smart packaging is advanced, it's simple. According to ABRE (2019), most smart packaging uses simple sensors, such as chemical and pH monitors, which interact with the internal atmosphere and detect the presence of gases, humidity, and other quality markers. The simplicity, ease and low cost that active and intelligent packaging brings, benefits the entire production chain, so that the industry can guarantee the preservation and quality of the product, thus having the ability to provide the best for the consumer, who will benefit from the practicality of having all the information about what makes up the product. about quality and preservation.

EDIBLE PACKAGING

Edible packaging can be used by the edible coatings applied directly to the food product or by the preformed films enclosing the product. Edible films can be produced by the wet process called casting or dry, known as extrusion. On an industrial scale, the most commonly used method is extrusion and spraying to deposition the coating on the surface of the product (SUHAG et al., 2020 apud ONGARATTO; VITAL; PRADO, 2022), as depicted in Figure 3:

Figure 3 - Waffles wrapped in packaging made of seaweed

Source: CHIABI, 2023.

PACKAGING WITH TIME/TEMPERATURE INDICATORS

Time and temperature indicators known as TTIs are smart devices that monitor and store the time and temperature history of the food, as well as show the consumer this information in real time. TTIs are based on chemical, enzymatic, microbiological or mechanical changes and can be produced as a label or label that provides rapid response to changes in storage temperature through changes in color and/or mechanical deformation and with respect to food quality (ONGARATTO; VITAL; PRADO, 2022).

An example of a commercialized TTI is from the 3M brand (Figure 4), which monitors when the temperature has been exceeded and displays an indicator that turns blue when exposed to the temperature above the recommended level. The principle of TTI is based on a porous strip indicating the path, with one end placed over a reservoir containing a blue chemical dye that has a certain melting point (ONGARATTO; VITAL; PRADO, p. 7, 2022), as shown in Figure 4.

Figure 4: Temperature Indicator3MTM (MonitorMark)

Source: ONGARATTO; VITAL; PRADO, p. 7, 2022.

INTERPRETIVE CENTERS

In the synthesis of this study, it is worth highlighting that the monitoring of the product through the packaging provides comfort and practicality, facilitating the daily life. The active action of preserving and prolonging the packaging ensures a healthier lifestyle, as it eliminates the need to add a high amount of harmful preservatives to the food. Efficiency comes with the best use of the contents of the packages, providing savings and avoiding waste (ONGARATTO; VITAL; PRADO, 2022).

While the technology used in active, smart packaging is advanced, it's simple. According to the Brazilian Packaging Association (ABRE, 2019), most smart packaging uses simple sensors, such as chemical and pH monitors, which interact with the internal atmosphere and detect the presence of gases, moisture, and other quality markers.

For the food industry, avoiding waste, reducing costs, and ensuring the quality of its product is extremely important. The application of nanotechnology will add value, due to low manufacturing costs, an example of which is the ceramic nanoparticle that can be formed on surfaces of volumetric materials using lower temperatures than other materials, thus reducing costs (HOSSAKI, VOLANTE, 2018).

In this approach, the contribution of ABRE (2019, n.p.) stands out, which states "the benefits of smart packaging are not restricted only to the delivery of a positive experience for the end consumer. By providing accurate product information, it becomes useful for the industry as a whole, from transportation to storage." In this way, it is clear that with technology, the possibilities and benefits that active and intelligent packaging can provide are wide-ranging. The use of nanotechnology and chemical elements are essential factors in the development of these packages.

Nanotechnology applied to food packaging has the potential to improve product safety, preservation, and quality. However, it is necessary to carry out a critical analysis to evaluate the possible impacts on human health and the environment, in addition to ensuring transparency and information to consumers about the use of these technologies. It is inferred that nano technology is providing significant results in the food market. However, it is essential to analyze on a large scale the consequence of nanotechnology, its positive and negative points for real improvement and innovation in the applications of such technology in the food area.

Through a systematic review of the literature (CROSSAN and APAYDIN, 2010) it was possible to identify the absence of specific regulation for nanofoods in Brazil, which compromises the right to information to the consuming public. It is valid to question the technical and historical issues of nanotechnology, its application in the food industry, risks associated with consumption and analysis of Brazilian public policies and bills on the subject. The authors, Fernandes and Oliveira (2019), highlight the legal importance in the face of the rise of nanotechnology in the food industry, emphasizing the need for regulation to ensure safety criteria and the consumer's right to choose.

From this perspective, it is essential to analyze concerns regarding human safety and health due to the possibility of releasing harmful substances into food. It is important to conduct proper research and regulations to ensure the safety of these packages. In addition, there are concerns about the toxicity of certain nanostructured materials and the potential adverse effects on human health and the ecosystem. It is important to conduct appropriate research and regulations to minimize the negative impacts of nanotechnology on the environment, which become a crucial precedent to ensure that innovations are safe and beneficial, while avoiding potential risk to human health. In this sense, according to Savolainen and Van Tassel, "the research carried out indicates that the nanometric scale of some artificial nanoparticles aggravates the risk of bioaccumulation of substances in the organs and tissues of the human body, which can lead to the development of diseases" (2013, p. 453 apud FERNANDES; OLIVEIRA, 2019). In addition, consumer awareness is crucial to ensure informed choice and to encourage transparency on the part of manufacturers.

In the scope of nanotechnology, it is worth highlighting nanotoxicology, which refers to the study of the toxic effects of nanomaterials on biological systems, and the complex interaction of these materials with cells, animals, humans and the environment is still an evolving field of research. Physicochemical and morphological properties of nanomaterials influence their interactions and, consequently, their toxicity. Research in this field is based on crucial parameters to determine nanoparticle doses and assess their toxicity accurately. However, it is essential to consider that protection against toxicity and the determination of maximum exposure values in humans depend on the advancement of studies in the area (DURÁN et al., 2019).

It is crucial not to allow the positive outlook of nanotechnology to prevail without proper reflection on the potential harm caused by nanomaterials on living organisms. Prior to approval for use, it is imperative to conduct a careful risk assessment, considering functionality and safety over the course of these new products in nano ratio. For this, it is necessary that regulations and standardizations be rigorously developed, especially in Brazil, where there is a great diversity ecosystems, with great potential to contribute materials to the creation of nanoproducts (CANCINO; MARANGONI; ZUCOLOTTO, 2018).

With everything, it is possible to infer that the incorporation of nanocomponents in the production of smart packaging for food storage signals the need to broaden the scientific and technological debate. The present and future impact of nanotechnology is undeniable, with advances already evident and promising to come. It is crucial to invest in research to understand the potential toxicological risks of nanomaterials and to establish effective international standards. In this way, we can ensure that nanotechnology is a positive force in the progress of future generations.

FINAL THOUGHTS

Nanotechnology applied to food packaging has the potential to improve product safety, preservation, and quality. However, it is necessary to carry out a critical analysis to assess the possible impacts on human health and the environment, as well as to ensure transparency and information to consumers about the use of these technologies. Along these lines, nanotechnology is one of the cutting-edge technologies today, and its applications in various areas open a fertile field for research and, consequently, for the advancement of science.

Nano technology is delivering significant results to the food market. However, it is essential to analyze on a large scale the consequence of nanotechnology, its positive and negative points for real improvement and innovation in the applications of such technology in the food area. In this aspect, Brazil's potential as a source of nanoproducts that will serve for the development of future nano technologies can be seen. It is ratified that technological development, especially in the area of nanotechnology, is crucial to face social problems, requiring constant improvement to reach its maximum potential, emphasizing the awareness of the importance of this subject in today's society, encouraging reflections on technological advances and their consequences.

Concluding this analysis on the applicability of nanotechnology in smart food packaging, it allows us to infer that the reflection on the development of mechanisms that can examine nutrients present or lack of them in food, becomes vital for the improvement in the process of creation and implementation of innovative products based on nanotechnology.

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