coatings

*Review*

# Smart Food Packaging: An Umbrella Review of Scientific Publications

**Fatma Boukid**

ClonBio Group Ltd., D02 XE61 Dublin, Ireland; fboukid@clonbioeng.com

**Abstract:** The pivotal roles of smart packaging in the food industry are ensuring food quality and safety as well as providing consumers with important information about the food, allowing them to make more informed purchase/consumption decisions. The purpose of this study is to provide a holistic bibliometric analysis of smart food packaging. Bibliometric analysis collected 878 documents from the Scopus database. The annual trend revealed a three-phase growth, i.e., initial (1986–1999), development (2000–2016), and exponential (2017–2022). Since 2017, smart food packaging has attracted increasing research interest. From the keywords analysis, similar general topics of research were identified before and after the coronavirus outbreak (COVID-19). Remarkably, COVID-19 accelerated research and development toward finding sustainable and safe bio-based materials. However, most smart packaging materials are still not commercialized mainly due to the high cost of production and the absence of international standard regulations. Overall, academia is steps ahead in commercialization, where novel materials and mechanisms are tested for their efficiency and safety. The widespread of smart packaging relies on finding sustainable and safe solutions that are feasible at large scale and accepted by consumers.

**Keywords:** food safety; sustainability; COVID-19; bibliometric analysis; biodegradable material; nanotechnology



**Citation:** Boukid, F. Smart Food Packaging: An Umbrella Review of Scientific Publications. *Coatings* **2022**, *12*, 1949. https://doi.org/10.3390/coatings12121949

Academic Editors: Cristina Anamaria Semeniuc, Dan Cristian Vodnar and Maria-Ioana Socaciu

Received: 23 November 2022
Accepted: 7 December 2022
Published: 12 December 2022



## 1. Introduction

Food packaging plays several pivotal roles in food protection, nutrient stability, and quality preservation. Moreover, it provides essential information about product shelf life, ingredients list, and nutritional labeling [1]. Nevertheless, the high amount of food packaging waste has increasingly become a serious environmental and economic burden [2]. It was recently reported that one-way packaging can represent up to half of the environmental impacts of the food value chain [3]. Therefore, shifting to reusable and recyclable packaging might contribute efficiently to waste management (e.g., plastic) [4]. This strategy aligns with Goal 11, Goal 12, Goal 14, and Goal 17 of the 2030 Sustainable Development Goals (SDGs). In 2019, the coronavirus pandemic (COVID-19) has disrupted food supply chains worldwide [5]. COVID-19 induced global health and economic crisis that had a major impact on consumer attitude, dietary habits and perception of food safety, and packaging [6–8]. Additionally, it contributed to putting upfront the shortcomings of classic packaging, such as limited control of product quality and safety, as well as traceability. For the post-COVID-19 era, new strategies are being implemented to leverage the innovation of packaging to fit new purposes beyond those classic strategies [9].

By definition, smart packaging refers to packaging systems with embedded sensor technology used for foods [10]. Compared to the classic one, smart packaging comes as an innovative strategy with additional functionalities to extend shelf life and monitor freshness, improving product safety, guaranteeing high-quality standards, as well as supporting sustainability all along the food production chain [11,12]. The market of smart packaging is witnessing a fast growth and was valued at USD 22,257.6 million in 2020 and is expected to reach USD 38,662.0 million by 2030 [13]. Active and intelligent packaging are two variants of smart packaging. Based on the European regulation (EC) No. 450/2009 [14], active packaging is a system designed to deliberately incorporate components that would release or absorb substances into or from the packaged food or from the environment surrounding the food. Although active packaging is not a new concept, it has significantly evolved during the last decades [15]. The use of natural biopolymers (e.g., protein, starches, and cellulose) in the packaging material with biological activities (e.g., antibacterial and antioxidants) regulates the environment inside the packaging, ensuring freshness and extending the shelf life of the food [16,17]. The European Food Safety Authority (EFSA) defined intelligent packaging as materials that monitor the condition of packaged food or the environment surrounding the food [18]. This packaging consists of indicators, biosensor or data carriers attached inside or on the surface of the food package [19]. This system can communicate the conditions of the packaged product and its history (pathogens, toxins, time, and temperature) to the consumers without interacting with the food [12,20,21].

Although extensive research is currently underway, not all the developed smart packaging systems have been implemented at an industrial scale [17,22]. Costs and time related with the research and development of new packaging materials are hampering the growth of the market [19]. The nature and complexity of packaging materials can cause safety issues and thus requires further trials to test their toxicity, which also requires proper regulation [11,12]. Additionally, integrating new packaging materials within the existing systems requires time and investments [20]. Therefore, there is plenty of room for innovation to reduce the gap between research and commercialization [23,24]. In this light, this study intends to thoroughly investigate the research landscape and trends of smart food packaging. Scopus is recognized as the largest abstract and citation database of peer-reviewed literature covering a wide-range of disciplines [25,26]. In this study, Scopus was used as the source of bibliometric records, while for the data visualization, VOSviewer was employed. Bibliometric analysis enables the assessment of scientific production and main topics related to the smart food packaging. This analysis has been widely implemented to evaluate academic outputs of various research fields [27–29]. The main goal of the bibliometric analysis is to analyze the growth of research, main topics, geographical distribution, scientific impact, and key actors in the field [27,29].

## 2. Methodology: Bibliometric Analysis

In this study, the literature dataset was collected from Scopus database. Scopus is a web-based, multidisciplinary database hosted by Elsevier, and it provides bibliometric data of peer-reviewed articles published in scientific, medical, technical, and social science disciplines. Scopus covers different subject areas, publication years, document types, indexed sources (22,000) from over 5000 publishers worldwide, patents and funding data. Compared to other bibliometric databases, Scopus (Elsevier's abstract and citation database) is a suitable database for the present study since it includes a multitude of fields, which is a mandatory criterion as proven by previous bibliometric studies [30,31].

On 29 October 2022, the literature search was conducted by entering the search queries (TITLE-ABS-KEY (smart AND packaging AND food)). Inclusion criteria were published records, including articles, comments, reviews, book chapters, and conference papers. With a further restriction to English as language, a total of 883 documents were collected. By setting the time span as ranging from 1986 to 2022, we obtained 878 documents. The collected documents were classified according to diverse aspects, i.e., number of documents per year, distribution by subject categories and by sources, and affiliation by country and institution. The final list of documents was analyzed using Microsoft Excel (Microsoft Office 365, Washington, WA, USA). In a second step, the final excel sheet was divided into two tables, publications before and after COVID-19. The cutoff was decided based on the first article mentioning COVID-19.

In regard to keywords analysis, 'all keywords' (meaning in the titles and abstracts of the selected documents) and 'authors keywords' were analyzed and charted using VOSviewer software, developed at Leiden University's Centre for Science and Technology

Studies, Leiden University, the Netherlands [32]. The VOSviewer charts were presented in bubbles and curved lines. The most used keywords were marked using larger circles. Different colors indicate different clusters with different keywords [32].

## 3. Results and Discussion

### *3.1. Annual Trend of Publications*

A total of 878 documents that met the research criteria were published from 1986 to 2022. Figure 1 visualizes the annual trend of the retrieved publications. The growth curve of scientific publications can be divided into three stages. During the initial phase, (from 1986 to 1999) the smart packaging concept was still seen as a futurist idea to overcome conventional packaging shortcomings. The second stage is characterized by a development phase that lasted from 2000 to 2016. During this period, the total number of publications was 247 documents. No clear trend was observed, with a fluctuation of the annual number of releases, in which the highest number of publications was recorded in 2015 (31 documents). The growing interest in smart food packaging could be fueled by the need of finding innovative solutions to overcome traditional packaging-related issues [33–35]. Owing to the continuously increasing customer experience expectations, the growing product complexity, and the waste reduction concerns, traditional packaging is no longer sufficiently adequate [36,37]. On the other hand, smart packaging enables changes (in the product and/or its environment) monitoring (intelligent packaging) and changes mitigation (active packaging) to provide a safe food product to consumers. Studies on nanomaterials applied in food packaging started to gain priority in research [37–39]. Moreover, the first generation of intelligent packaging emerged to solve safety and quality issues through the supply chain, and to reduce product losses [40].

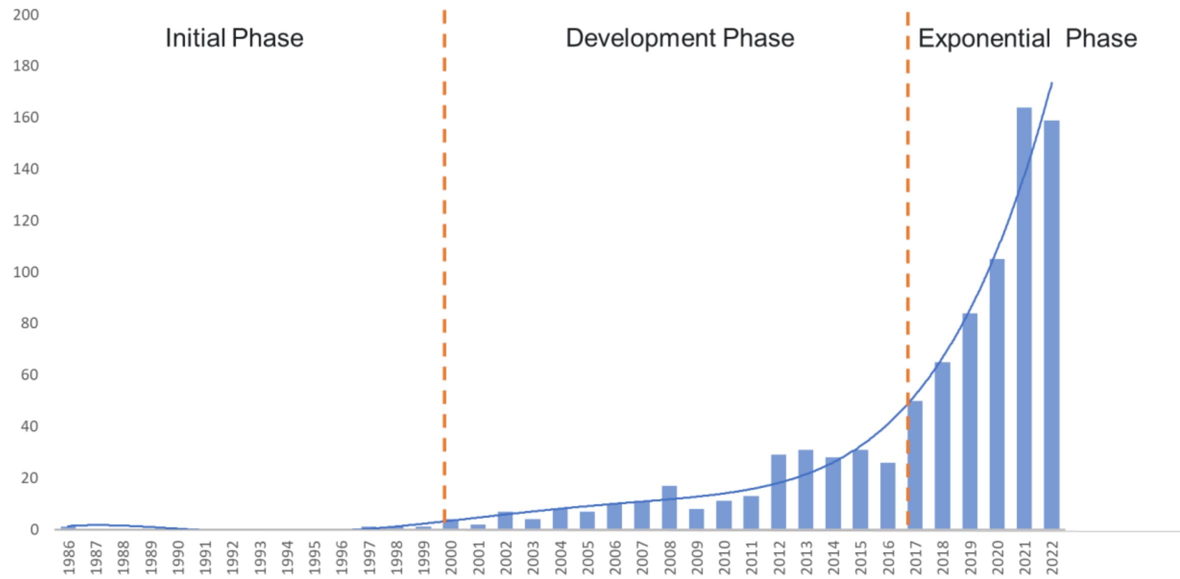


**Figure 1.** Annual trend of smart food packaging publications.

Exponential phase is the third ongoing stage and it started since 2017. A dramatic growth of interest from the academia was observed showing a booming trend in scientific publications. Advances in materials and engineering also contributed to boost research in this sector [41–43]. New technologies, such as nanotechnology and artificial intelligence, offered new materials/films to improve safety and quality of foods with an extended shelf life [16,41]. Various nanomaterials are being studied to provide active, bio-based, and smart/intelligent packaging [44,45]. Several research funding calls, such as HORIZON-JU-CBE-2022 and H2020-JTI-BBI-2020, have been supporting projects with the aim of preserving/improving food quality and reducing food waste. In addition, bio-based packaging is gaining a lot of interest to replace conventional plastic. For instance, USABLE

PACKAGING project and DanuBioValNet project are EU funded ongoing projects focused on levitating bio-based packaging.

### 3.2. Subject Categories

The total research areas identified were 26 and of these 21 had at least 10 publications. The top 20 research areas with the highest number of publications are illustrated in Table 1. The most prominent areas on smart packaging are Engineering, Agricultural and Biological Sciences, Materials Science and Chemistry, and Biochemistry, Genetics and Molecular Biology.

**Table 1.** Main subject area related to smart food packaging, as classified by Scopus [1].

| Rank | Subject Area | Documents | Record (%) |
|---|---|---|---|
| 1 | Engineering | 320 | 36.4% |
| 2 | Agricultural and Biological Sciences | 313 | 35.6% |
| 3 | Materials Science | 248 | 28.2% |
| 4 | Chemistry | 181 | 20.6% |
| 5 | Biochemistry, Genetics and Molecular Biology | 177 | 20.2% |
| 6 | Chemical Engineering | 119 | 13.6% |
| 7 | Physics and Astronomy | 102 | 11.6% |
| 8 | Medicine | 79 | 9.0% |
| 9 | Environmental Science | 70 | 8.0% |
| 10 | Computer Science | 58 | 6.6% |
| 11 | Energy | 48 | 5.5% |
| 12 | Economics, Econometrics and Finance | 39 | 4.4% |
| 13 | Pharmacology, Toxicology and Pharmaceutics | 32 | 3.6% |
| 14 | Business, Management and Accounting | 31 | 3.5% |
| 15 | Social Sciences | 31 | 3.5% |
| 16 | Immunology and Microbiology | 28 | 3.2% |
| 17 | Nursing | 17 | 1.9% |
| 18 | Earth and Planetary Sciences | 15 | 1.7% |
| 19 | Mathematics | 13 | 1.5% |
| 20 | Health Professions | 12 | 1.4% |

[1] more than one can apply.

### 3.3. Most Prolific Countries and Institutions

A total of 79 countries participated in publishing the retrieved documents. Particularly, 30 countries had more than 10 publications. The top 20 prolific countries are shown in Table 2. India was the most prolific (119 publications) and was followed by the USA (112 publications), China (94 publications), and Italy (56 publications).

### 3.4. Most Prolific Institutions

In total, 150 institutions have contributed to the total record. However, only 9 of them had more than 10 publications, as illustrated in Table 3. Urmia University was the most prolific, with 28 publications. Other prolific institutions included Tabriz University of Medical Sciences (19 documents), University College Cork (16 documents), Kyung Hee University (13 documents), University of Massachusetts Amherst (13 documents), and Consiglio Nazionale delle Ricerche (13 documents).

**Table 2.** The top prolific countries.

| Rank | Country/Territory | Documents | Record (%) |
|---|---|---|---|
| 1 | India | 119 | 13.6% |
| 2 | USA | 112 | 12.8% |
| 3 | China | 94 | 10.7% |
| 4 | Italy | 56 | 6.4% |
| 5 | Iran | 54 | 6.2% |
| 6 | Spain | 45 | 5.1% |
| 7 | United Kingdom | 44 | 5.0% |
| 8 | South Korea | 42 | 4.8% |
| 9 | Brazil | 37 | 4.2% |
| 10 | Indonesia | 33 | 3.8% |
| 11 | Ireland | 30 | 3.4% |
| 12 | Portugal | 28 | 3.2% |
| 13 | Turkey | 27 | 3.1% |
| 14 | Canada | 23 | 2.6% |
| 15 | Greece | 23 | 2.6% |
| 16 | Australia | 21 | 2.4% |
| 17 | Malaysia | 20 | 2.3% |
| 18 | Egypt | 15 | 1.7% |
| 19 | Germany | 15 | 1.7% |
| 20 | Thailand | 14 | 1.6% |

**Table 3.** The top prolific institutions.

| | Institution | Country | Documents | Record (%) |
|---|---|---|---|---|
| 1 | Urmia University | Iran | 28 | 3.2% |
| 2 | Tabriz University of Medical Sciences | Iran | 19 | 2.3% |
| 3 | University College Cork | Ireland | 16 | 1.8% |
| 4 | Kyung Hee University | Republic of Korea | 13 | 1.5% |
| 5 | University of Massachusetts Amherst | USA | 13 | 1.5% |
| 6 | Consiglio Nazionale delle Ricerche | Italy | 13 | 1.5% |
| 7 | Ministry of Education China | China | 11 | 1.3% |
| 8 | CSIC–Instituto de Agroquímica y Tecnología de los Alimentos IATA | Spain | 11 | 1.3% |
| 9 | Tehran University of Medical Sciences | Iran | 11 | 1.3% |
| 10 | Universidade do Minho | Portugal | 9 | 1.1% |
| 11 | Hasanuddin University | Indonesia | 9 | 1.0% |
| 12 | Yonsei University Mirae Campus | Republic of Korea | 9 | 1.0% |
| 13 | Rutgers University–New Brunswick | USA | 9 | 1.0% |
| 14 | School of Public Health | USA | 9 | 1.0% |
| 15 | Consejo Nacional de Investigaciones Científicas y Técnicas | Spain | 8 | 1.0% |
| 16 | Gorgan University of Agricultural Sciences and Natural Resources | Iran | 8 | 0.9% |
| 17 | Universidade de Vigo | Spain | 8 | 0.9% |
| 18 | Clemson University | USA | 8 | 0.9% |
| 19 | Universitas Jember | Indonesia | 8 | 0.9% |
| 20 | National Technical University of Athens | Greece | 7 | 0.8% |

### 3.5. Key Actors

In the list of relevant authors associated with smart food packaging, out of 2860 authors, 5 authors had more than 10 publications (Table 4).

**Table 4.** Most relevant authors by publications.

| Authors | Affiliation | Documents |
|---|---|---|
| Kerry, J. | Department of Food and Nutritional Sciences, University College Cork, National University of Ireland, Cork, Ireland | 15 |
| Rhim, J.W. | Department of Food and Nutrition, BioNanocomposite Research Center, Kyung Hee University, 26 Kyungheedae-ro, Dongdaemun-gu, Seoul 02447, South Korea | 12 |
| Moradi, M. | Department of Food Hygiene and Quality Control, Faculty of Veterinary Medicine, Urmia University, Urmia, Iran | 11 |
| Liu, J. | College of Food Science and Engineering, Yangzhou University, Yangzhou 225127, PR China | 10 |
| McClements, D.J. | Department of Food Science, University of Massachusetts Amherst, Amherst, MA 01003, USA | 10 |

Dr. Kerry, J. is one of the main actors, who has worked on food (meat products) smart packaging and biodegradable materials [36,46].

Dr. Moradi, M. stands out for his research in regard to the use of nanotechnology and electrospinning to develop films for active and intelligent packaging [42,47].

Dr. Rhim, J.W. has focused on bio-nanocomposites for food packaging applications [39,48].

Dr. Liu, J. has worked on developing active and intelligent packaging films using biomaterials [49,50].

Dr. McClements, D.J. has contributed by research to nanomaterials and their use in developing smart packaging [51,52].

### 3.6. Most Prolific Journals

A total of 878 publications were published in 123 journals. Of these, 11 journals had at least 10 published articles. Table 5 shows the 10 most featured journals. From the analysis, the "International Journal of Biological Macromolecules" had the highest number of publications (40), followed by Food Packaging And Shelf Life, Trends In Food Science And Technology, Food Hydrocolloids, and Food Control.

### 3.7. Keywords Analysis

Scientific studies have used keywords to classify recent topics of interest in regard to smart packaging in the food industry. In this study, 6634 keywords resulted from the VOSviewer analysis of all keywords, while those relative to the author were 2246. Using all of them with a threshold of 20 occurrences, 82 keywords were found to meet this threshold and the strength of the links between their co-occurrence (Figure 2). As a result, three main clusters represented with three different colors (i.e., green, red, and blue) were identified. These clusters are closely related as illustrated in Figure 2.

Red showed general topics in regard to smart packaging and its role in the food supply chain. This cluster included words, such as active packaging, nanotechnology, modified atmosphere, food preservation, food processing, food microbiology, quality control, food labeling, food waste, food quality, and human. Remarkably, although intelligent packaging was among the list of 82 keywords used in Figure 2, it was not shown unlike active packaging. This suggests that more research is focused on active packaging compared to intelligent packaging since it has a longer history [40,44].

**Table 5.** The top prolific journals.

| Rank | Source | Publisher, Country | Documents | Record (%) |
|---|---|---|---|---|
| 1 | International Journal Of Biological Macromolecules | Elsevier (Netherlands) | 40 | 4.6% |
| 2 | Food Packaging And Shelf Life | Elsevier (Netherlands) | 16 | 1.8% |
| 3 | Trends In Food Science And Technology | Elsevier (Netherlands) | 16 | 1.8% |
| 4 | Food Hydrocolloids | Elsevier (Netherlands) | 15 | 1.7% |
| 5 | Food Control | Elsevier (Netherlands) | 14 | 1.6% |
| 6 | Iop Conference Series Earth And Environmental Science | IOP Publishing (UK) | 13 | 1.5% |
| 7 | Food Chemistry | Elsevier (Netherlands) | 12 | 1.4% |
| 8 | Critical Reviews In Food Science And Nutrition | Taylor and Francis Ltd. (USA) | 11 | 1.3% |
| 9 | Sensors And Actuators B: Chemical | Elsevier (Netherlands) | 11 | 1.3% |
| 10 | Carbohydrate Polymers | Elsevier (Netherlands) | 10 | 1.1% |
| 11 | Polymers | MDPI (Switzerland) | 10 | 1.1% |
| 12 | Food Research International | Elsevier (Netherlands) | 9 | 1.0% |
| 13 | Foods | MDPI (Switzerland) | 9 | 1.0% |
| 14 | Nanomaterials | MDPI (Switzerland) | 9 | 1.0% |
| 15 | Packaging Technology And Science | Wiley (USA) | 9 | 1.0% |
| 16 | Materials | MDPI (Switzerland) | 8 | 0.9% |
| 17 | Acta Horticulturae | International Society for Horticultural Science (Belgium) | 7 | 0.8% |
| 18 | Diabetes Self Management | SAGE Publications Inc. (USA) | 7 | 0.8% |
| 19 | Food And Bioprocess Technology | Springer Nature (Switzerland) | 7 | 0.8% |
| 20 | Molecules | MDPI (Switzerland) | 7 | 0.8% |

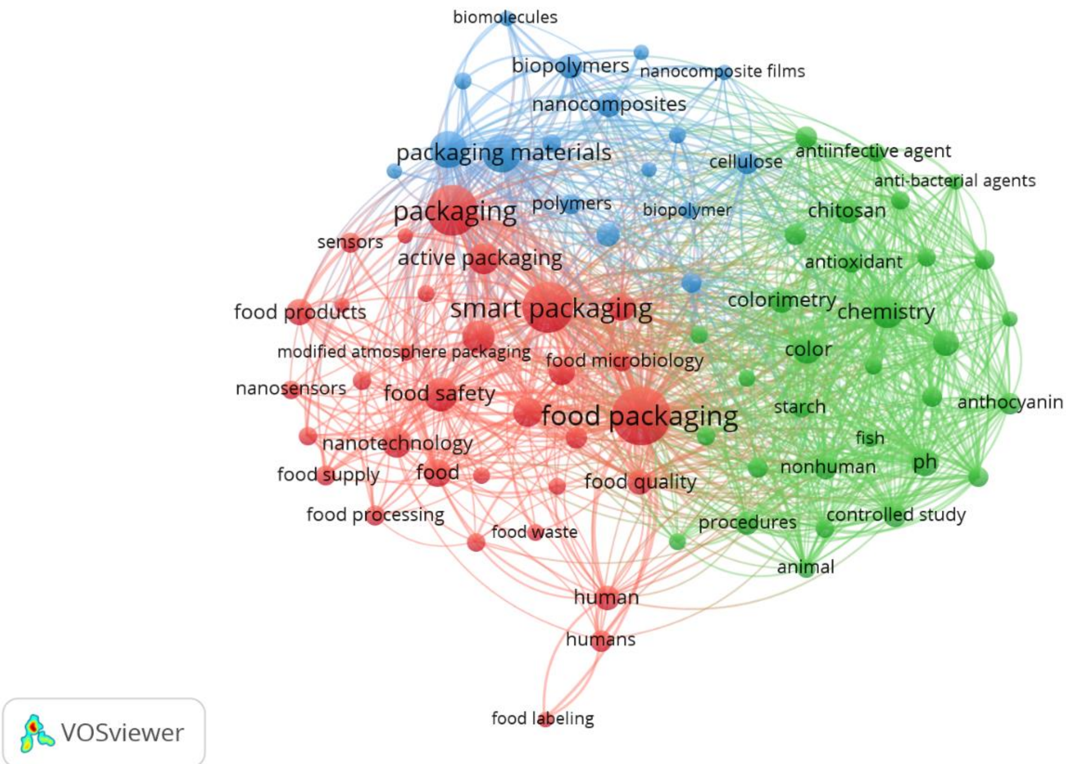


**Figure 2.** Word cloud based on the main keywords (82 words for a threshold of 20 publications each) related to smart food packaging. Figure drawn by VOSviewer [32].

Blue consisted of keywords, such as biomolecules, biopolymers, and nanocomposite packaging materials. This underlines the current direction in research and proposals aiming at the promotion of naturally sourced materials to create packaging of foods [39,53–55]. Growing concerns over the environment and sustainability related to artificial materials are boosting scientists to find eco-friendly films [17,53,56].

Green showed specific natural compounds used in developing smart food packaging. This reflects the increased interest in biodegradable packaging materials, including anthocyanin, starch, cellulose, and chitosan [57]. Polysaccharides are versatile, biodegradable, non-toxic, affordable, sustainable, and available polymers [43,53,54]. Cellulose and chitosan are widely used for food packaging due to their good film and gel-forming ability, recyclability, and inherent antimicrobial properties [24,58,59]. Starches can be used for food packaging as an adhesive and additive but the mechanical properties of the resulting films still have some limitations [59–61]. Overall, some biomaterials have brittle texture, fast aging, and poor mechanical properties [62]. Therefore, scientists continue to search for solutions to improve their features. Creating a combination of compounds with complementary attributes resulted in films with enhanced mechanical properties [62–64]. For instance, polysaccharides have attracted extensive attention as a film-forming material for active and intelligent colorimetric packaging with the addition of anthocyanins [65]. Anthocyanins are pH-sensitive to the environment and thus are used in developing pH responsive smart films [66–68]. Colorimetric films can realize/facilitate real-time monitoring of food freshness [60,69,70]. At present, the use of anthocyanins in active and smart packaging films has attracted increasing attention in the field of food engineering [63,71]. Other pigments, such as curcumin, shikonin, alizarin, and betalain, with similar features to anthocyanins are used as freshness indicator films [55,72,73].

Using authors' keyword options and a threshold of 6 publications, 69 keywords were found (Figure 3). In contrast to Figure 2, the authors' keywords (Figure 3) captured more specifically the current research directions in the smart food packaging.

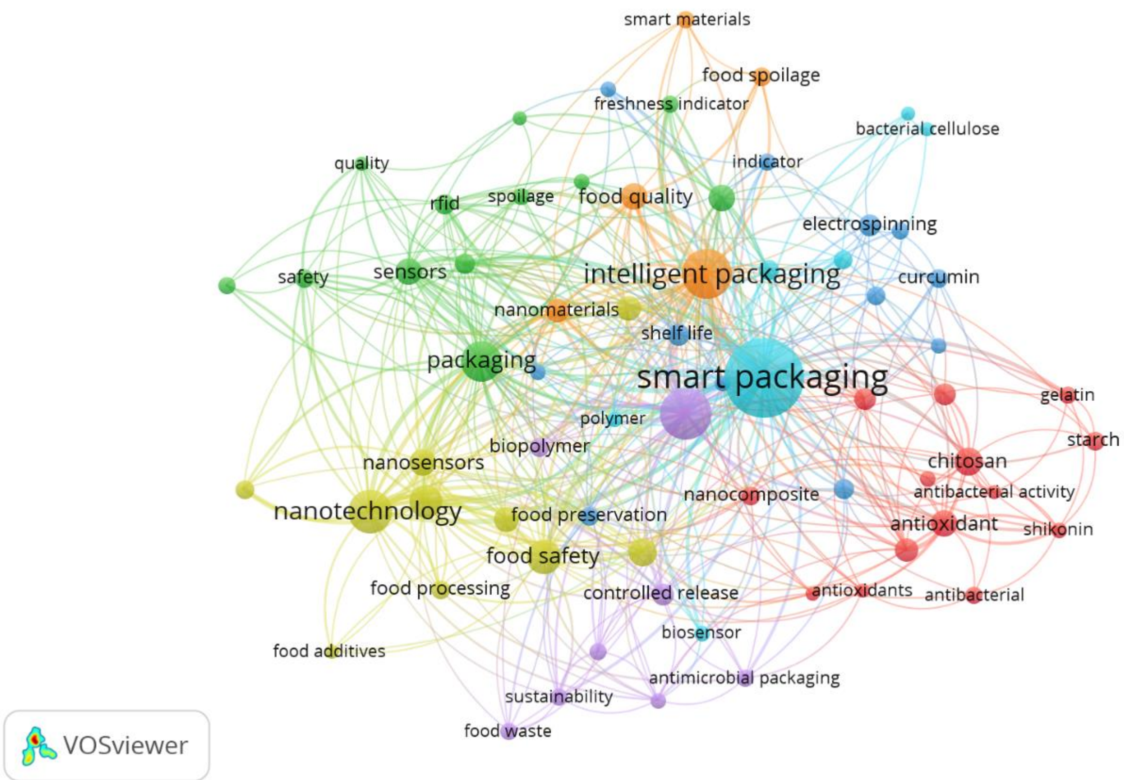


**Figure 3.** Word cloud based on the authors' keywords (69 words) related to smart food packaging. Figure drawn by VOSviewer [32].

Authors' keyword clouds were clustered in seven groups/colors:

1. Turquoise is the main cluster with "smart packaging" as the main keyword. This cluster contains works, such as "bacterial cellulose" and "biosensors".
2. Orange covers keywords related to intelligent packaging with words, such as "nanomaterials", "smart material", "food spoilage", and "food quality".
3. Blue is closely related to the turquoise and orange clusters and includes keywords, such as "indicator", "freshness indicator", "electrospinning", "curcumin", and "shelf life".
4. Purple focuses on polymers and biopolymers related to food waste, sustainability, controlled release, and antimicrobial packaging.
5. Green focuses on mechanisms of smart packaging and their safety with words, such as "quality", "safety", "spoilage", "sensors", and radio-frequency identification "RFID".
6. Yellow had nanotechnology as a central nod. This cluster contained words, such as "nano sensors", "food preservation", "safety", "food additives", and "processing". This reflects the interest in this technology in nanomaterials for developing intelligent packaging.
7. Red consisted of words related to packaging biomaterials with keywords, including "chitosan", "starch", "gelatin", and their properties (i.e., antioxidant and antibacterial).

*3.8. Impact of COVID-19 on Research Topics*

Total publications (n = 878) were divided into two groups, i.e., before (n = 606) and after (n = 272) COVID-19. The total keywords before COVID-19 were 4484, while after COVID-19 were 3235. Using a threshold of 20 occurrences, 39 keywords were retained for the pre-COVID-19 period and 31 for post-COVID-19 (Figure 4).

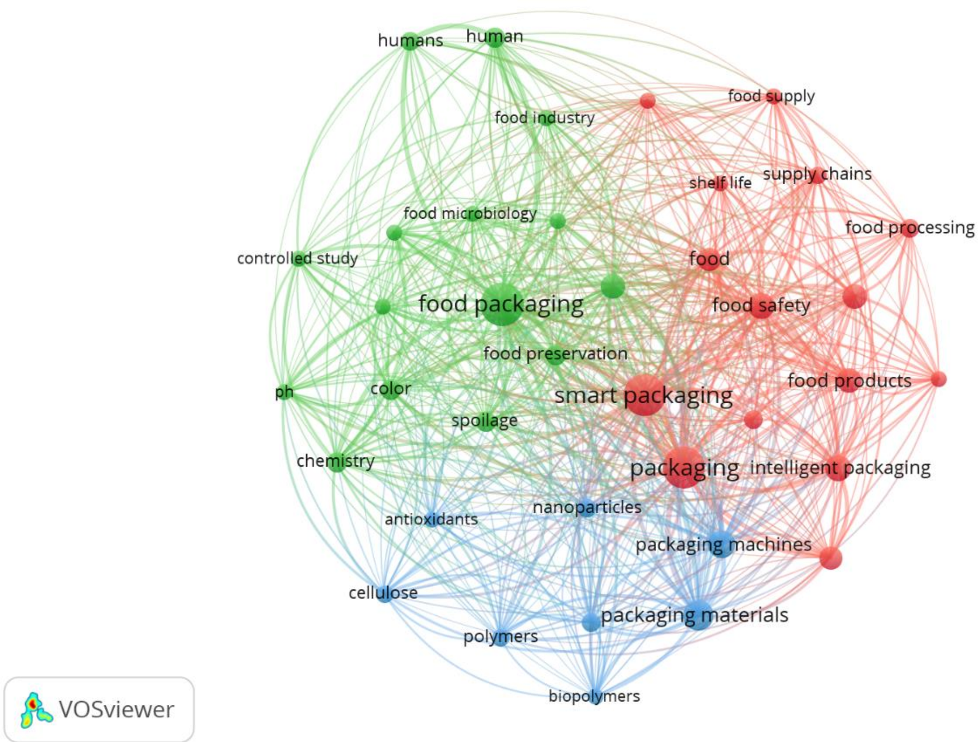


**Figure 4.** Word cloud based on all keywords related to smart food packaging during pre-COVID-19. Figure drawn by VOSviewer [32].

For the pre-COVID-19 era, three main clusters (i.e., green, red, and blue) were identified. Blue was focused on packaging materials, such as nanoparticles and biomaterials (cellulose). Red was related to the importance of smart and intelligent packaging in food preservation and safety all along the production chain. Green focused on food control and the impact of food packaging on human health. Overall, academia was more focused on packaging materials in relatedness to food safety [38,74,75]. To ensure the safety of packaging materials in contact with food, regulatory authorities have developed guidelines and regulations for the risk assessment [37,75]. Nevertheless, this latter is not universal, but different systems have been developed around the world by agencies, such as Food and Drug Administration (FDA, USA), Health Canada, and the European Commission [76–78]. In August 2009, EFSA published guidelines regarding the submission of dossiers for the safety assessment of active and intelligent substances used in food packaging in Europe [79].

For the post-COVID-19 era (Figure 5), researchers' interest was focused first on the packaging role in food preservation and storage (green color). The unexpected emergence of the COVID-19 pandemic has changed the behavior of customers [80–82]. People tended to stockpile and buy more than they can consume due to the increased risk of shortages during the sanitary crisis [82,83]. This has urged more research to understand the impact of different types of packaging on food quality in association with innovative processing, such as nanotechnology [16,84]. Red cluster gathers packaging materials and biomaterials, such as anthocyanins and chitosan and their bioactive activities in the food, as well as chemical materials. This cluster contained the mode of detection, which is mostly chemical reactions related to pH and color change. H ions and ammonia are also among the identified keywords, and they are concrete examples of the color change on the intelligent indicator used for monitoring meat quality during storage. The use of smart packaging in meat products has been studied in several publications [69,85–87]. Meat is a staple food characterized by a high perishability [88]. During storage, the decomposition of fresh and processed meat products by enzymes and microbes produces volatile ammonia compounds, which are early indicators of quality/safety damage. Protein degradation during meat storage leads to the generation of ammonia, which is responsible for pH increase. Here, this volatile nitrogenous compound reacts with H+ ions and produces H ions [89]. The OH ions in the packaging are directly proportional to the pH value, which affect the change in the intelligent indicator [90].

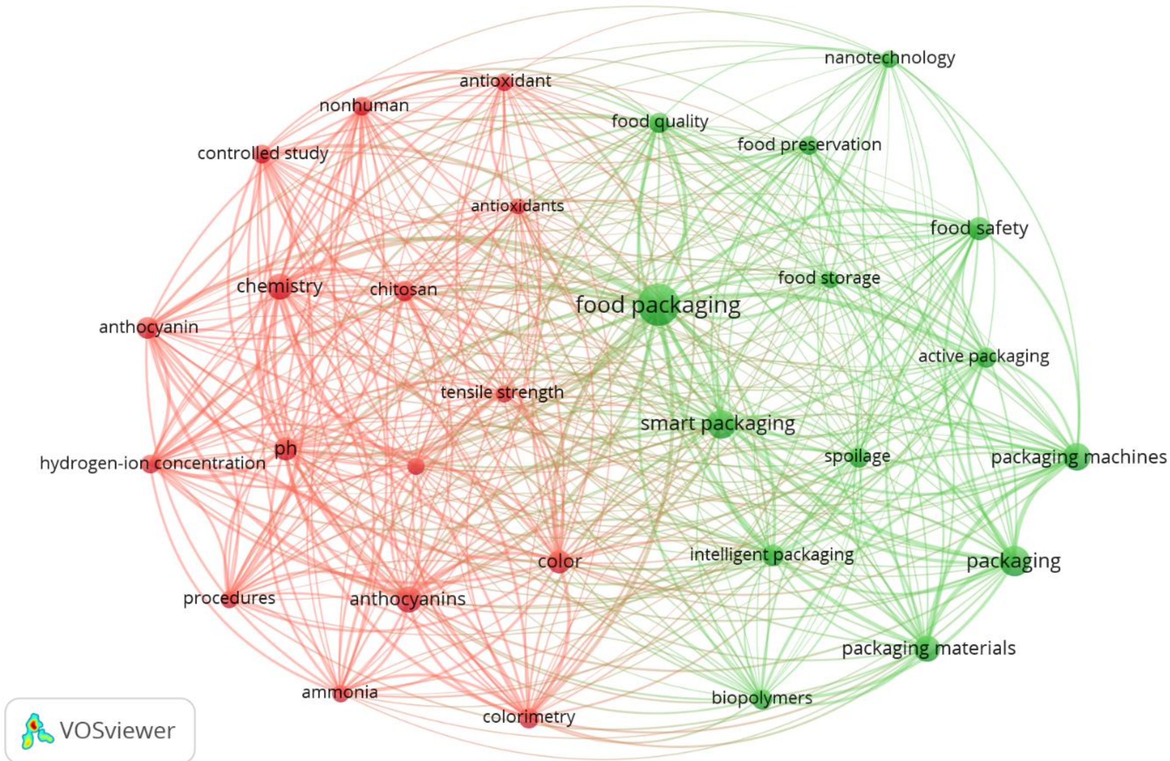


**Figure 5.** Word cloud based on all keywords related to smart food packaging during post-COVID-19. Figure drawn by VOSviewer [32].

In regard to authors' keywords, 1399 were found pre-COVID-19 versus 1070 post-COVID-19. Considering a threshold of 6 publications, 35 keywords were retrieved for pre-COVID-19 compared to 27 after the pandemic. Figure 6 shows six clusters. Yellow has the central nod presenting smart packaging with keywords related to biopolymers, food quality, and nanocomposite. This cluster is connected to the light blue cluster that includes encapsulations and biosensors. Red and purple are connected and related to intelligent packaging types (sensors and indicators) and their role in food safety and food waste. Post-COVID-19, biodegradable material appeared among the most used keywords by authors (Figure 7, blue cluster). This suggests the shift toward more sustainable materials for environmental motives and increased awareness in finding solutions [12,17]. Green covered keywords related to the use of chitosan in making nanoparticles/material for packaging. However, post-COVID-19 research shows a higher diversity in biomaterials, such as starch, curcumin, anthocyanin, and shikonin (Figure 7). Blue is more of a holistic cluster showing topics related to agriculture, food, and packaging technology. Overall, the main topics related to food safety and packaging materials are remained the same before and after COVID-19. Nevertheless, more biomaterial is being studied after COVID-19 with the focus on food safety [8,91,92]. Probably, this is due to the increased pressure as a result of the international crisis, such as COVID-19 and wars to develop safe (for humans and planet) biomaterials for commercialization and their more broad use [91,93].

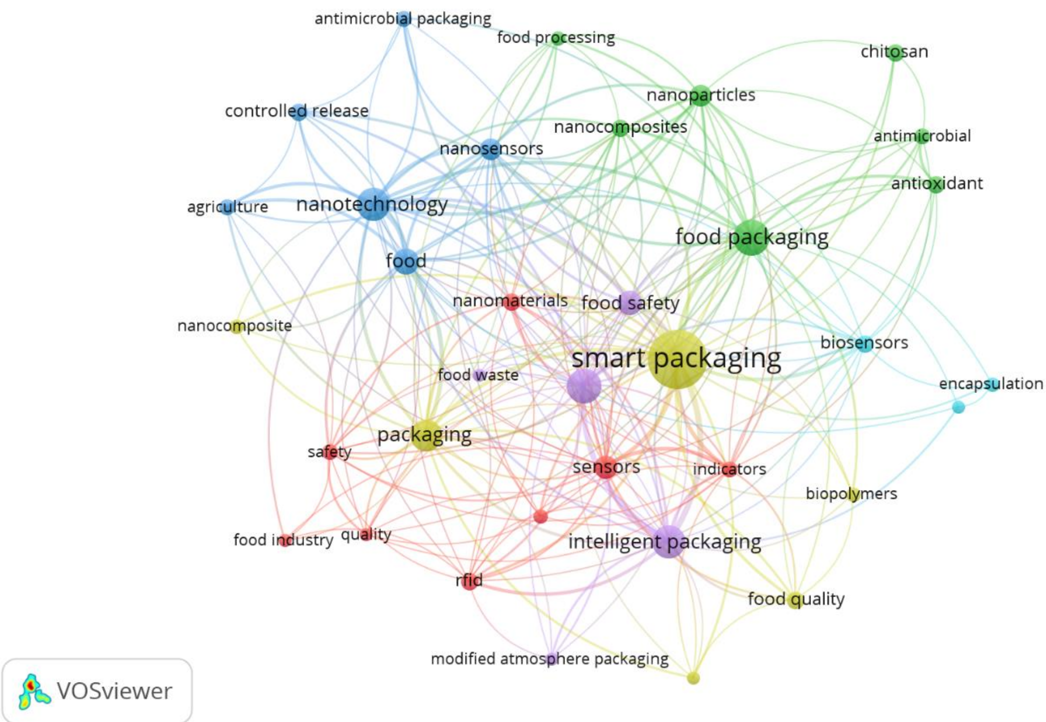


**Figure 6.** Word cloud based on authors' keywords related to smart food packaging during pre-COVID-19. Figure drawn by VOSviewer [32].

### *3.9. Challenges and Opportunities*

Opportunities rely on the use of biomaterials with ingredients having bioactive activities, such as antioxidant and antimicrobial. Nanotechnology and electrospinning are contributing in making these bioactive nanoparticles with multifunctionality [16,94,95]. Further research is still needed for producing new packages from health beneficial sources. COVID-19 reinforced the urgent need for packaging biomaterials ensuring safety, convenience, and sustainability (Figure 8). The increased awareness on the association between food quality and safety, as well as health urged consumers' demand for more information about what they are eating [8,91]. Smart packaging offering traceability and real-time information regarding the products would be beneficial for providing valuable safety information to consumers. Ecofriendly claims are attracting consumers due to increased awareness toward the impact of plastic on the environment [17,96]. This could encourage consumers to pay more for these types of products. E-commerce packaging has grown steadily in recent years, especially after COVID-19 [96]. Improved control and tracking of foods can be performed using intelligent packaging.

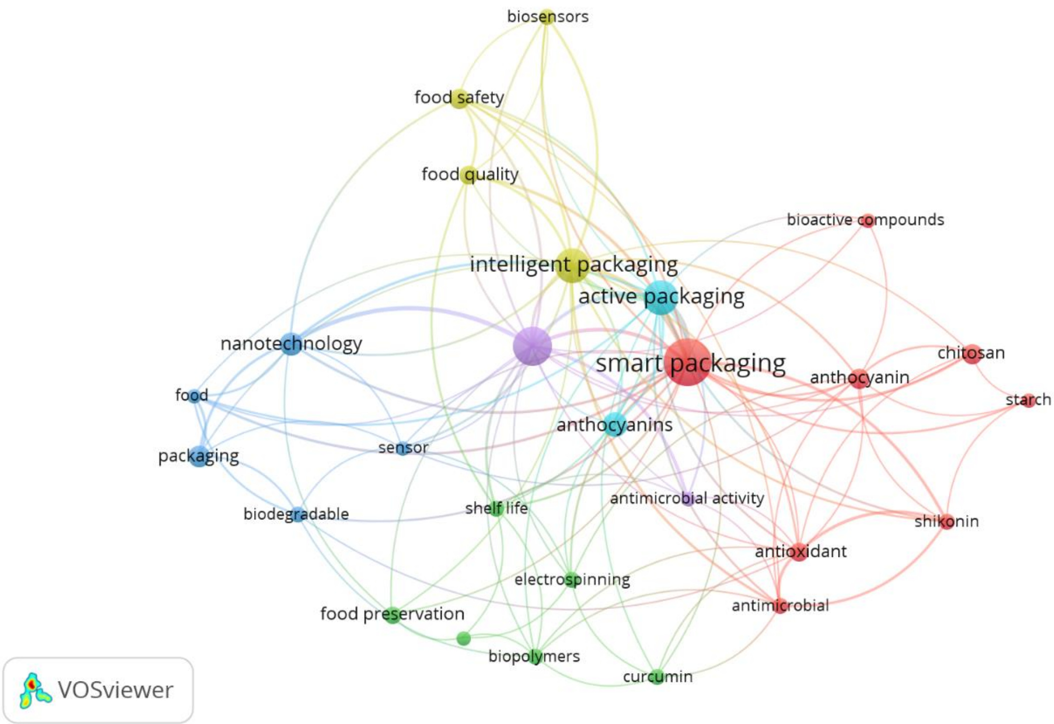


**Figure 7.** Word cloud based on authors' keywords related to smart food packaging during post-COVID-19. Figure drawn by VOSviewer [32].

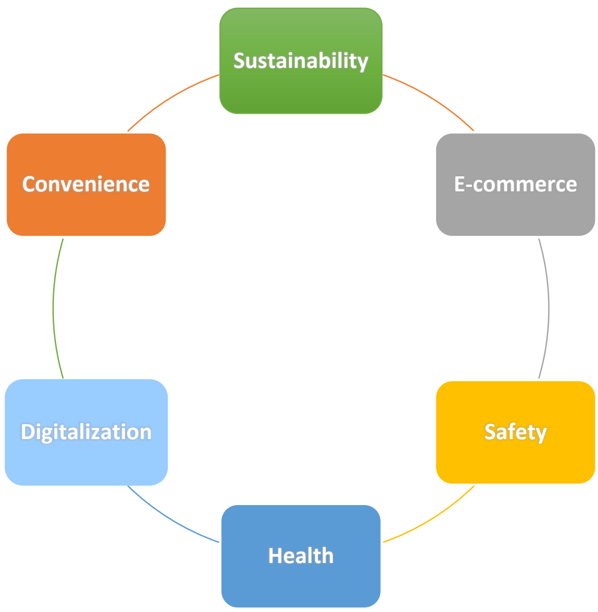


**Figure 8.** Opportunities and challenges of smart food packaging.

Smart food packaging is facing several challenges. The safety of bioactive material is a key factor to boost the shift from lab to industrial scale. There is still a need for guidelines with clear specifications and analyses to show the safety of material used in packaging. Mass production is still challenging, and solutions are required to reduce the cost, while being environmentally friendly, as well as safe for use by humans. The recovery of bioactive ingredients from agro-industrial by-products can represent a solution to develop nanoparticles [48,97]. For instance, in the EU, large amounts of vegetable by-products rich in carotenoids might contribute to the reduction in the cost of developing active packaging. The fast evolution in digitalization, such as artificial intelligence and sensors would support a faster growth in intelligent packaging materials [98,99]. Proving feasibility and cost effectiveness will boost the progress of this type of packaging as a good candidate to ensure food safety and quality. Moreover, 3D printing would support the designing and executing of custom-made films that fit with the product requirements [100,101].

## 4. Conclusions

In conclusion, smart food packaging is not a new concept, but it is increasingly considered as an effective solution to ensure food quality and safety. Currently, at academic level, it is in the development phase where different topics are being studied. The main research topics are food safety, packaging materials, health, sustainability, and food preservation. When dividing the scientific literatures in two groups, pre- and post-COVID-19, the main topics are the same, but a trend toward sustainable solutions, such as the use of biodegradable materials is more accentuated after COVID-19. This underlines that this moment of crisis ensured more recognition of the benefits of active and intelligent packaging technologies. The challenges are related to the economic feasibility and scalability of smart food packaging. Global times of crisis, including the pandemic and armed conflicts, are stimulating factors to policy makers, manufacturers, and regulatory authorities to join efforts toward the faster development of smart food packaging.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

## References

1. Pascall, M.A.; DeAngelo, K.; Richards, J.; Arensberg, M.B. Role and Importance of Functional Food Packaging in Specialized Products for Vulnerable Populations: Implications for Innovation and Policy Development for Sustainability. *Foods* **2022**, *11*, 3043. [CrossRef] [PubMed]
2. Ncube, L.K.; Ude, A.U.; Ogunmuyiwa, E.N.; Zulkifli, R.; Beas, I.N. An Overview of Plastic Waste Generation and Management in Food Packaging Industries. *Recycling* **2021**, *6*, 12. [CrossRef]
3. Bala, A.; Laso, J.; Abejón, R.; Margallo, M.; Fullana-i-Palmer, P.; Aldaco, R. Environmental Assessment of the Food Packaging Waste Management System in Spain: Understanding the Present to Improve the Future. *Sci. Total Environ.* **2020**, *702*, 134603. [CrossRef] [PubMed]
4. Arunan, I.; Crawford, R.H. Greenhouse Gas Emissions Associated with Food Packaging for Online Food Delivery Services in Australia. *Resour. Conserv. Recycl.* **2021**, *168*, 105299. [CrossRef]
5. Galanakis, C.M. The Food Systems in the Era of the Coronavirus (COVID-19) Pandemic Crisis. *Foods* **2020**, *9*, 523. [CrossRef]
6. Iftekhar, A.; Cui, X. Blockchain-Based Traceability System That Ensures Food Safety Measures to Protect Consumer Safety and COVID-19 Free Supply Chains. *Foods* **2021**, *10*, 1289. [CrossRef]
7. Pascuta, M.S.; Vodnar, D.C. Nanocarriers for Sustainable Active Packaging: An Overview during and Post COVID-19. *Coatings* **2022**, *12*, 102. [CrossRef]
8. Kitz, R.; Walker, T.; Charlebois, S.; Music, J. Food Packaging during the COVID-19 Pandemic: Consumer Perceptions. *Int. J. Consum. Stud.* **2022**, *46*, 434–448. [CrossRef]
9. Echegaray, F. What POST-COVID-19 Lifestyles May Look like? Identifying Scenarios and Their Implications for Sustainability. *Sustain. Prod. Consum.* **2021**, *27*, 567. [CrossRef]
10. Schaefer, D.; Cheung, W.M. Smart Packaging: Opportunities and Challenges. *Procedia CIRP* **2018**, *72*, 1022–1027. [CrossRef]

11. Kamer, D.D.A.; Kaynarca, G.B.; Yücel, E.; Gümüş, T. Development of Gelatin/PVA Based Colorimetric Films with a Wide PH Sensing Range Winery Solid by-Product (Vinasse) for Monitor Shrimp Freshness. *Int. J. Biol. Macromol.* **2022**, *220*, 627–637. [CrossRef] [PubMed]
12. Chen, S.; Brahma, S.; Mackay, J.; Cao, C.; Aliakbarian, B. The Role of Smart Packaging System in Food Supply Chain. *J. Food Sci.* **2020**, *85*, 517–525. [CrossRef]
13. Allied Market Research Smart Packaging Market Size, Growth and Forecast to 2030. Available online: https://www.alliedmarketresearch.com/smart-packaging-market (accessed on 17 November 2022).
14. European Parliament Commission Regulation (EC) No 450/2009 of 29 May 2009 on Active and Intelligent Materials and Articles Intended to Come into Contact with Food. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009R0450&from=EN (accessed on 9 December 2022).
15. Flores, Y.; Pelegrín, C.J.; Ramos, M.; Jiménez, A.; Garrigós, M.C. Use of Herbs and Their Bioactive Compounds in Active Food Packaging. *Aromat. Herbs Food Bioact. Compd. Process. Appl.* **2021**, *5*, 323–365. [CrossRef]
16. Lamri, M.; Bhattacharya, T.; Boukid, F.; Chentir, I.; Dib, A.L.; Das, D.; Djenane, D.; Gagaoua, M. Nanotechnology as a Processing and Packaging Tool to Improve Meat Quality and Safety. *Foods* **2021**, *10*, 2633. [CrossRef] [PubMed]
17. Song, T.; Qian, S.; Lan, T.; Wu, Y.; Liu, J.; Zhang, H. Recent Advances in Bio-Based Smart Active Packaging Materials. *Foods* **2022**, *11*, 2228. [CrossRef] [PubMed]
18. EFSA. Guidelines on Submission of a Dossier for Safety Evaluation by the EFSA of Active or Intelligent Substances Present in Active and Intelligent Materials and Articles Intended to Come into Contact with Food. *EFSA J.* **2009**, *7*, 1–10. [CrossRef]
19. Pou, K.R.J.; Raghavan, V.; Packirisamy, M. Microfluidics in Smart Packaging of Foods. *Food Res. Int.* **2022**, *161*, 111873. [CrossRef]
20. Müller, P.; Schmid, M. Intelligent Packaging in the Food Sector: A Brief Overview. *Foods* **2019**, *8*, 16. [CrossRef]
21. Biji, K.B.; Ravishankar, C.N.; Mohan, C.O.; Srinivasa Gopal, T.K. Smart Packaging Systems for Food Applications: A Review. *J. Food Sci. Technol.* **2015**, *52*, 6125. [CrossRef]
22. Jafarzadeh, S.; Jafari, S.M.; Salehabadi, A.; Nafchi, A.M.; Uthaya Kumar, U.S.; Khalil, H.P.S.A. Biodegradable Green Packaging with Antimicrobial Functions Based on the Bioactive Compounds from Tropical Plants and Their By-Products. *Trends Food Sci. Technol.* **2020**, *100*, 262–277. [CrossRef]
23. Zhong, Y.; Godwin, P.; Jin, Y.; Xiao, H. Biodegradable Polymers and Green-Based Antimicrobial Packaging Materials: A Mini-Review. *Adv. Ind. Eng. Polym. Res.* **2020**, *3*, 27–35. [CrossRef]
24. Brandelli, A. The Interaction of Nanostructured Antimicrobials with Biological Systems: Cellular Uptake, Trafficking and Potential Toxicity. *Food Sci. Hum. Wellness* **2020**, *9*, 8–20. [CrossRef]
25. Tunger, D.; Eulerich, M. Bibliometric Analysis of Corporate Governance Research in German-Speaking Countries: Applying Bibliometrics to Business Research Using a Custom-Made Database. *Scientometrics* **2018**, *117*, 2041–2059. [CrossRef]
26. Donthu, N.; Kumar, S.; Pandey, N. A Retrospective Evaluation of Marketing Intelligence and Planning: 1983–2019. *Mark. Intell. Plan.* **2021**, *39*, 48–73. [CrossRef]
27. Boukid, F.; Sogari, G.; Rosell, C.M. Edible Insects as Foods: Mapping Scientific Publications and Product Launches in the Global Market (1996–2021). *J. Insects Food Feed* **2022**, 1–16. [CrossRef]
28. Villaró, S.; Ciardi, M.; Morillas-España, A.; Sánchez-Zurano, A.; Acién-Fernández, G.; Lafarga, T. Microalgae Derived Astaxanthin: Research and Consumer Trends and Industrial Use as Food. *Foods* **2021**, *10*, 2303. [CrossRef]
29. Duque-Acevedo, M.; Belmonte-Ureña, L.J.; Cortés-García, F.J.; Camacho-Ferre, F. Agricultural Waste: Review of the Evolution, Approaches and Perspectives on Alternative Uses. *Glob. Ecol. Conserv.* **2020**, *22*, e00902. [CrossRef]
30. Mishra, H.G.; Pandita, S.; Bhat, A.A.; Mishra, R.K.; Sharma, S. Tourism and Carbon Emissions: A Bibliometric Review of the Last Three Decades: 1990–2021. *Tour. Rev.* **2022**, *77*, 636–658. [CrossRef]
31. Montoya-Torres, J.R.; Muñoz-Villamizar, A.; Mejia-Argueta, C. Mapping Research in Logistics and Supply Chain Management during COVID-19 Pandemic. *Int. J. Logist. Res.* **2021**, 1–21. [CrossRef]
32. Van Eck, N.J.; Waltman, L. Software Survey: VOSviewer, a Computer Program for Bibliometric Mapping. *Scientometrics* **2010**, *84*, 523–538. [CrossRef]
33. Macé, S.; Cornet, J.; Chevalier, F.; Cardinal, M.; Pilet, M.F.; Dousset, X.; Joffraud, J.J. Characterisation of the Spoilage Microbiota in Raw Salmon (Salmo Salar) Steaks Stored under Vacuum or Modified Atmosphere Packaging Combining Conventional Methods and PCR–TTGE. *Food Microbiol.* **2012**, *30*, 164–172. [CrossRef]
34. Nychas, G.J.E.; Skandamis, P.N. Fresh Meat Spoilage and Modified Atmosphere Packaging (MAP). *Improv. Saf. Fresh Meat* **2005**, 461–502. [CrossRef]
35. O'Grady, M.N.; Kerry, J.P. Smart Packaging Technologies and Their Application in Conventional Meat Packaging Systems. *Meat Biotechnol.* **2008**, 425–451. [CrossRef]
36. Kerry, J.P.; O'Grady, M.N.; Hogan, S.A. Past, Current and Potential Utilisation of Active and Intelligent Packaging Systems for Meat and Muscle-Based Products: A Review. *Meat Sci.* **2006**, *74*, 113–130. [CrossRef] [PubMed]
37. Silvestre, C.; Duraccio, D.; Cimmino, S. Food Packaging Based on Polymer Nanomaterials. *Prog. Polym. Sci.* **2011**, *36*, 1766–1782. [CrossRef]
38. Singh Sekhon, B. Nanotechnology in Agri-Food Production: An Overview. *Nanotechnol. Sci. Appl.* **2014**, *7*, 31–53. [CrossRef]
39. Rhim, J.W.; Park, H.M.; Ha, C.S. Bio-Nanocomposites for Food Packaging Applications. *Prog. Polym. Sci.* **2013**, *38*, 1629–1652. [CrossRef]

40. Vanderroost, M.; Ragaert, P.; Devlieghere, F.; De Meulenaer, B. Intelligent Food Packaging: The next Generation. *Trends Food Sci. Technol.* **2014**, *39*, 47–62. [CrossRef]
41. Salgado, P.R.; Di Giorgio, L.; Musso, Y.S.; Mauri, A.N. Recent Developments in Smart Food Packaging Focused on Biobased and Biodegradable Polymers. *Front. Sustain. Food Syst.* **2021**, *5*, 125. [CrossRef]
42. Forghani, S.; Almasi, H.; Moradi, M. Electrospun Nanofibers as Food Freshness and Time-Temperature Indicators: A New Approach in Food Intelligent Packaging. *Innov. Food Sci. Emerg. Technol.* **2021**, *73*, 102804. [CrossRef]
43. Youssef, A.M.; El-Sayed, S.M. Bionanocomposites Materials for Food Packaging Applications: Concepts and Future Outlook. *Carbohydr. Polym.* **2018**, *193*, 19–27. [CrossRef] [PubMed]
44. Chausali, N.; Saxena, J.; Prasad, R. Recent Trends in Nanotechnology Applications of Bio-Based Packaging. *J. Agric. Food Res.* **2022**, *7*, 100257. [CrossRef]
45. Madhusudan, P.; Chellukuri, N.; Shivakumar, N. Smart Packaging of Food for the 21st Century - A Review with Futuristic Trends, Their Feasibility and Economics. *Mater. Today Proc.* **2018**, *5*, 21018–21022. [CrossRef]
46. Tyuftin, A.A.; Kerry, J.P. Review of Surface Treatment Methods for Polyamide Films for Potential Application as Smart Packaging Materials: Surface Structure, Antimicrobial and Spectral Properties. *Food Packag. Shelf Life* **2020**, *24*, 100475. [CrossRef]
47. Moradi, M.; Kousheh, S.A.; Razavi, R.; Rasouli, Y.; Ghorbani, M.; Divsalar, E.; Tajik, H.; Guimarães, J.T.; Ibrahim, S.A. Review of Microbiological Methods for Testing Protein and Carbohydrate-Based Antimicrobial Food Packaging. *Trends Food Sci. Technol.* **2021**, *111*, 595–609. [CrossRef]
48. Roy, S.; Rhim, J.W. Anthocyanin Food Colorant and Its Application in PH-Responsive Color Change Indicator Films. *Crit. Rev. Food Sci. Nutr.* **2021**, *61*, 2297–2325. [CrossRef]
49. Yong, H.; Liu, J. Recent Advances in the Preparation, Physical and Functional Properties, and Applications of Anthocyanins-Based Active and Intelligent Packaging Films. *Food Packag. Shelf Life* **2020**, *26*, 100550. [CrossRef]
50. Jin, K.; Tang, Y.; Liu, J.; Wang, J.; Ye, C. Nanofibrillated Cellulose as Coating Agent for Food Packaging Paper. *Int. J. Biol. Macromol.* **2021**, *168*, 331–338. [CrossRef]
51. McClements, D.J.; Xiao, H. Is Nano Safe in Foods? Establishing the Factors Impacting the Gastrointestinal Fate and Toxicity of Organic and Inorganic Food-Grade Nanoparticles. *NPJ Sci. Food* **2017**, *1*, 1–13. [CrossRef]
52. Cheng, H.; Chen, L.; McClements, D.J.; Yang, T.; Zhang, Z.; Ren, F.; Miao, M.; Tian, Y.; Jin, Z. Starch-Based Biodegradable Packaging Materials: A Review of Their Preparation, Characterization and Diverse Applications in the Food Industry. *Trends Food Sci. Technol.* **2021**, *114*, 70–82. [CrossRef]
53. Bhargava, N.; Sharanagat, V.S.; Mor, R.S.; Kumar, K. Active and Intelligent Biodegradable Packaging Films Using Food and Food Waste-Derived Bioactive Compounds: A Review. *Trends Food Sci. Technol.* **2020**, *105*, 385–401. [CrossRef]
54. Roohi, S.P.; Bano, K.; Zaheer, M.R.; Kuddus, M. Biodegradable Smart Biopolymers for Food Packaging: Sustainable Approach toward Green Environment. In *Bio-Based Materials for Food Packaging: Green and Sustainable Advanced Packaging Materials*; Springer: Singapore, 2018; pp. 197–216. ISBN 9789811319099.
55. Abelti, A.L.; Abera Teka, T.; Fikreyesus Forsedo, S.; Tamiru, M.; Bultosa, G.; Alkhtib, A.; Burton, E. Bio-Based Smart Materials for Fish Product Packaging: A Review. *Int. J. Food Prop.* **2022**, *25*, 857–871. [CrossRef]
56. Ahmed, I.; Lin, H.; Zou, L.; Li, Z.; Brody, A.L.; Qazi, I.M.; Lv, L.; Pavase, T.R.; Khan, M.U.; Khan, S.; et al. An Overview of Smart Packaging Technologies for Monitoring Safety and Quality of Meat and Meat Products. *Packag. Technol. Sci.* **2018**, *31*, 449–471. [CrossRef]
57. Atta, O.M.; Manan, S.; Shahzad, A.; Ul-Islam, M.; Ullah, M.W.; Yang, G. Biobased Materials for Active Food Packaging: A Review. *Food Hydrocoll.* **2022**, *125*, 107419. [CrossRef]
58. Perez Espitia, P.J.; Du, W.X.; Avena-Bustillos, R.d.J.; Ferreira Soares, N.d.F.; McHugh, T.H. Edible Films from Pectin: Physical-Mechanical and Antimicrobial Properties—A Review. *Food Hydrocoll.* **2014**, *35*, 287–296. [CrossRef]
59. Kovačević, K.; Karadžić, M.; Banjac, K.; Yan, M.R.; Hsieh, S.; Ricacho, N. Innovative Food Packaging, Food Quality and Safety, and Consumer Perspectives. *Processes* **2022**, *10*, 747. [CrossRef]
60. Luchese, C.L.; Abdalla, V.F.; Spada, J.C.; Tessaro, I.C. Evaluation of Blueberry Residue Incorporated Cassava Starch Film as PH Indicator in Different Simulants and Foodstuffs. *Food Hydrocoll.* **2018**, *82*, 209–218. [CrossRef]
61. Yoon, S.D.; Park, M.H.; Byun, H.S. Mechanical and Water Barrier Properties of Starch/PVA Composite Films by Adding Nano-Sized Poly(Methyl Methacrylate-Co-Acrylamide) Particles. *Carbohydr. Polym.* **2012**, *87*, 676–686. [CrossRef]
62. Li, S.; Jiang, Y.; Zhou, Y.; Li, R.; Jiang, Y.; Alomgir Hossen, M.; Dai, J.; Qin, W.; Liu, Y. Facile Fabrication of Sandwich-like Anthocyanin/Chitosan/Lemongrass Essential Oil Films via 3D Printing for Intelligent Evaluation of Pork Freshness. *Food Chem.* **2022**, *370*, 131082. [CrossRef]
63. Fernández-Marín, R.; Fernandes, S.C.M.; Sánchez, M.Á.A.; Labidi, J. Halochromic and Antioxidant Capacity of Smart Films of Chitosan/Chitin Nanocrystals with Curcuma Oil and Anthocyanins. *Food Hydrocoll.* **2022**, *123*, 107119. [CrossRef]
64. Gasti, T.; Dixit, S.; D'souza, O.J.; Hiremani, V.D.; Vootla, S.K.; Masti, S.P.; Chougale, R.B.; Malabadi, R.B. Smart Biodegradable Films Based on Chitosan/Methylcellulose Containing Phyllanthus Reticulatus Anthocyanin for Monitoring the Freshness of Fish Fillet. *Int. J. Biol. Macromol.* **2021**, *187*, 451–461. [CrossRef] [PubMed]
65. Zhang, K.; Huang, T.S.; Yan, H.; Hu, X.; Ren, T. Novel PH-Sensitive Films Based on Starch/Polyvinyl Alcohol and Food Anthocyanins as a Visual Indicator of Shrimp Deterioration. *Int. J. Biol. Macromol.* **2020**, *145*, 768–776. [CrossRef] [PubMed]

66. Luchese, C.L.; Frick, J.M.; Patzer, V.L.; Spada, J.C.; Tessaro, I.C. Synthesis and Characterization of Biofilms Using Native and Modified Pinhão Starch. *Food Hydrocoll.* **2015**, *45*, 203–210. [CrossRef]
67. Chen, S.; Wu, M.; Lu, P.; Gao, L.; Yan, S.; Wang, S. Development of PH Indicator and Antimicrobial Cellulose Nanofibre Packaging Film Based on Purple Sweet Potato Anthocyanin and Oregano Essential Oil. *Int. J. Biol. Macromol.* **2020**, *149*, 271–280. [CrossRef]
68. Liu, Y.; Qin, Y.; Bai, R.; Zhang, X.; Yuan, L.; Liu, J. Preparation of PH-Sensitive and Antioxidant Packaging Films Based on κ-Carrageenan and Mulberry Polyphenolic Extract. *Int. J. Biol. Macromol.* **2019**, *134*, 993–1001. [CrossRef]
69. Santos, L.G.; Alves-Silva, G.F.; Martins, V.G. Active-Intelligent and Biodegradable Sodium Alginate Films Loaded with Clitoria Ternatea Anthocyanin-Rich Extract to Preserve and Monitor Food Freshness. *Int. J. Biol. Macromol.* **2022**, *220*, 866–877. [CrossRef]
70. da Silva, H.M.; Mageste, A.B.; e Silva, S.J.B.; Dias Ferreira, G.M.; Ferreira, G.M.D. Anthocyanin Immobilization in Carboxymethylcellulose/Starch Films: A Sustainable Sensor for the Detection of Al(III) Ions in Aqueous Matrices. *Carbohydr. Polym.* **2020**, *230*, 115679. [CrossRef]
71. Zhao, L.; Liu, Y.; Zhao, L.; Wang, Y. Anthocyanin-Based PH-Sensitive Smart Packaging Films for Monitoring Food Freshness. *J. Agric. Food Res.* **2022**, *9*, 100340. [CrossRef]
72. Priyadarshi, R.; Ezati, P.; Rhim, J.W. Recent Advances in Intelligent Food Packaging Applications Using Natural Food Colorants. *ACS Food Sci. Technol.* **2021**, *1*, 124–138. [CrossRef]
73. Alizadeh-Sani, M.; Mohammadian, E.; Rhim, J.W.; Jafari, S.M. PH-Sensitive (Halochromic) Smart Packaging Films Based on Natural Food Colorants for the Monitoring of Food Quality and Safety. *Trends Food Sci. Technol.* **2020**, *105*, 93–144. [CrossRef]
74. Ravichandran, R. Nanotechnology Applications in Food and Food Processing: Innovative Green Approaches, Opportunities and Uncertainties for Global Market. *Int. J. Green Nanotechnol. Phys. Chem.* **2010**, *1*, P72–P96. [CrossRef]
75. He, X.; Deng, H.; Hwang, H. min The Current Application of Nanotechnology in Food and Agriculture. *J. Food Drug Anal.* **2019**, *27*, 1–21. [CrossRef] [PubMed]
76. Muncke, J.; Backhaus, T.; Geueke, B.; Maffini, M.V.; Martin, O.V.; Myers, J.P.; Soto, A.M.; Trasande, L.; Trier, X.; Scheringer, M. Scientific Challenges in the Risk Assessment of Food Contact Materials. *Environ. Health Perspect.* **2017**, *125*, 095001. [CrossRef] [PubMed]
77. Karmaus, A.L.; Osborn, R.; Krishan, M. Scientific Advances and Challenges in Safety Evaluation of Food Packaging Materials: Workshop Proceedings. *Regul. Toxicol. Pharmacol.* **2018**, *98*, 80–87. [CrossRef] [PubMed]
78. Magnuson, B.; Munro, I.; Abbot, P.; Baldwin, N.; Lopez-Garcia, R.; Ly, K.; McGirr, L.; Roberts, A.; Socolovsky, S. Review of the Regulation and Safety Assessment of Food Substances in Various Countries and Jurisdictions. *Food Addit. Contam. Part A Chem. Anal. Control. Expo. Risk Assess.* **2013**, *30*, 1147. [CrossRef] [PubMed]
79. EFSA Active and Intelligent Packaging Substances | EFSA. Available online: https://www.efsa.europa.eu/en/topics/topic/active-and-intelligent-packaging-substances (accessed on 23 November 2022).
80. Janssen, M.; Chang, B.P.I.; Hristov, H.; Pravst, I.; Profeta, A.; Millard, J. Changes in Food Consumption During the COVID-19 Pandemic: Analysis of Consumer Survey Data from the First Lockdown Period in Denmark, Germany, and Slovenia. *Front. Nutr.* **2021**, *8*, 60. [CrossRef]
81. Hassoun, A.; Bekhit, A.E.D.; Jambrak, A.R.; Regenstein, J.M.; Chemat, F.; Morton, J.D.; Gudjónsdóttir, M.; Carpena, M.; Prieto, M.A.; Varela, P.; et al. The Fourth Industrial Revolution in the Food Industry—Part II: Emerging Food Trends. *Crit. Rev. Food Sci. Nutr.* **2022**, 1–31. [CrossRef]
82. Bender, K.E.; Badiger, A.; Roe, B.E.; Shu, Y.; Qi, D. Consumer Behavior during the COVID-19 Pandemic: An Analysis of Food Purchasing and Management Behaviors in U.S. Households through the Lens of Food System Resilience. *Socioecon. Plann. Sci.* **2022**, *82*, 101107. [CrossRef]
83. Kabadurmus, O.; Kayikci, Y.; Demir, S.; Koc, B. A Data-Driven Decision Support System with Smart Packaging in Grocery Store Supply Chains during Outbreaks. *Socioecon. Plann. Sci.* **2022**, 101417. [CrossRef]
84. Thirumalai, A.; Harini, K.; Pallavi, P.; Gowtham, P.; Girigoswami, K.; Girigoswami, A. Nanotechnology Driven Improvement of Smart Food Packaging. *Mater. Res. Innov.* **2022**. [CrossRef]
85. Liu, J.; Li, K.; Chen, Y.; Ding, H.; Wu, H.; Gao, Y.; Huang, S.; Wu, H.; Kong, D.; Yang, Z.; et al. Active and Smart Biomass Film Containing Cinnamon Oil and Curcumin for Meat Preservation and Freshness Indicator. *Food Hydrocoll.* **2022**, *133*, 107979. [CrossRef]
86. Dirpan, A.; Djalal, M.; Kamaruddin, I. Application of an Intelligent Sensor and Active Packaging System Based on the Bacterial Cellulose of Acetobacter Xylinum to Meat Products. *Sensors* **2022**, *22*, 544. [CrossRef] [PubMed]
87. Tahir, H.E.; Hashim, S.B.H.; Komla Mahunu, G.; Arslan, M.; Jiyong, S.; Adam Mariod, A.; Zhang, J.; El-Seedi, H.R.; Zhai, X.; Musa, T.H.; et al. Smart Films Fabricated from Natural Pigments for Measurement of Total Volatile Basic Nitrogen (TVB-N) Content of Meat for Freshness Evaluation: A Systematic Review. *Food Chem.* **2022**, *396*, 133674. [CrossRef] [PubMed]
88. Raimondi, S.; Nappi, M.R.; Sirangelo, T.M.; Leonardi, A.; Amaretti, A.; Ulrici, A.; Magnani, R.; Montanari, C.; Tabanelli, G.; Gardini, F.; et al. Bacterial Community of Industrial Raw Sausage Packaged in Modified Atmosphere throughout the Shelf Life. *Int. J. Food Microbiol.* **2018**, *280*, 78–86. [CrossRef] [PubMed]
89. Alizadeh-Sani, M.; Tavassoli, M.; Mohammadian, E.; Ehsani, A.; Khaniki, G.J.; Priyadarshi, R.; Rhim, J.W. PH-Responsive Color Indicator Films Based on Methylcellulose/Chitosan Nanofiber and Barberry Anthocyanins for Real-Time Monitoring of Meat Freshness. *Int. J. Biol. Macromol.* **2021**, *166*, 741–750. [CrossRef]

90. Dirpan, A.; Djalal, M.; Ainani, A.F. A Simple Combination of Active and Intelligent Packaging Based on Garlic Extract and Indicator Solution in Extending and Monitoring the Meat Quality Stored at Cold Temperature. *Foods* **2022**, *11*, 1495. [CrossRef]
91. Anvar, A.A.; Ahari, H.; Ataee, M. Antimicrobial Properties of Food Nanopackaging: A New Focus on Foodborne Pathogens. *Front. Microbiol.* **2021**, *12*, 690706. [CrossRef]
92. Parashar, N.; Hait, S. Plastics in the Time of COVID-19 Pandemic: Protector or Polluter? *Sci. Total Environ.* **2021**, *759*, 144274. [CrossRef]
93. Amorim, A.; Barbosa, A.d.H.; do Amaral Sobral, P.J. Hunger, Obesity, Public Policies, and Food-Based Dietary Guidelines: A Reflection Considering the Socio-Environmental World Context. *Front. Nutr.* **2022**, *8*, 805569. [CrossRef]
94. O'Callaghan, K.A.M.; Kerry, J.P. Consumer Attitudes towards the Application of Smart Packaging Technologies to Cheese Products. *Food Packag. Shelf Life* **2016**, *9*, 1–9. [CrossRef]
95. Kuswandi, B.; Moradi, M. Improvement of Food Packaging Based on Functional Nanomaterial. In *Nanotechnology: Applications in Energy, Drug and Food*; Springer: Cham, Switzerland, 2019; pp. 309–344. [CrossRef]
96. Escursell, S.; Llorach-Massana, P.; Roncero, M.B. Sustainability in E-Commerce Packaging: A Review. *J. Clean. Prod.* **2021**, *280*, 124314. [CrossRef]
97. Priyadarshi, R.; Rhim, J.W. Chitosan-Based Biodegradable Functional Films for Food Packaging Applications. *Innov. Food Sci. Emerg. Technol.* **2020**, *62*, 102346. [CrossRef]
98. Pirola, F.; Boucher, X.; Wiesner, S.; Pezzotta, G. Digital Technologies in Product-Service Systems: A Literature Review and a Research Agenda. *Comput. Ind.* **2020**, *123*, 103301. [CrossRef]
99. Lenka, S.; Parida, V.; Wincent, J. Digitalization Capabilities as Enablers of Value Co-Creation in Servitizing Firms. *Psychol. Mark.* **2017**, *34*, 92–100. [CrossRef]
100. Chong, W.J.; Shen, S.; Li, Y.; Trinchi, A.; Pejak, D.; Kyratzis, I.L.; Sola, A.; Wen, C. Additive Manufacturing of Antibacterial PLA-ZnO Nanocomposites: Benefits, Limitations and Open Challenges. *J. Mater. Sci. Technol.* **2022**, *111*, 120–151. [CrossRef]
101. Ma, Y.; Yang, W.; Xia, Y.; Xue, W.; Wu, H.; Li, Z.; Zhang, F.; Qiu, B.; Fu, C. Properties and Applications of Intelligent Packaging Indicators for Food Spoilage. *Membranes* **2022**, *12*, 477. [CrossRef]