Future Foods 6 (2022) 100191

Contents lists available at ScienceDirect

Future Foods

journal homepage: www.elsevier.com/locate/fufo

Consumer behavior towards nanopackaging - A new trend in the food industry

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ARTICLE INFO

Keywords:
Food packaging
Industry 4.0
Nanotechnology
Socio-psychological factors
Sustainable packaging

ABSTRACT

Packaging is a key tool to serve as a vehicle for communication between customers and the food industry. The food industry is continually investigating new technologies to improve and promote new food packaging aspects. Currently, nanotechnology has become one of the most promising trends for food packaging. This systematic review aims to elaborate on the scientific research progress of consumer behavior toward nanopackaging. Social and psychological motivations for consumers toward the new trend were discussed. This paper synthesizes various numbers of studies, especially during the digital era of Industry 4.0. The application of nanotechnology for food packaging has led to the development of active, smart, and bioactive nanopackaging, which includes nanoantimicrobials, nanosensors, and nanobarcodes. Studies showed that consumer social and psychological factors influence directly or indirectly the application of nanopackaging. Social norms, social concerns, and social media behavior are the social factors that drive consumer behavior. Moreover, motivation, perception, learning, attitudes and beliefs, personality, and habits are the main psychological factors driving the consumer decision on buying or adopting the new trend in food packaging. The understanding of these social and psychological factors is crucial for manufacturers and governments in developing strategies to alleviate the consumers' negative feedback and reduce their unfamiliarity with the new trends in food consumption, especially nanopackaging. In the future, efforts supported by scientific evidence should be made to increase the awareness, knowledge and trust of consumers to improve their perception of sustainable packaging solutions.

Introduction

In the last decade, population growth and changes in lifestyle have led to increased demand for ready-to-eat foods. We are witnessing the availability of a multitude of processed and packed foods on the market, which unsurprisingly leads to nutrition troubles. Diets have become less and less balanced and the prevalence of diseases linked to the consumption of unbalanced diets has increased. Studies have shown the causality relationships between dietary patterns and lifestyle habits versus chronic illnesses. For instance, the increased intake of processed and calorie-dense foods has led to increasing rates of overweight and obesity across countries worldwide (WHO, 2021). Based on this situation, more

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https://doi.org/10.1016/j.fufo.2022.100191
Received 7 June 2022; Received in revised form 12 August 2022; Accepted 21 September 2022

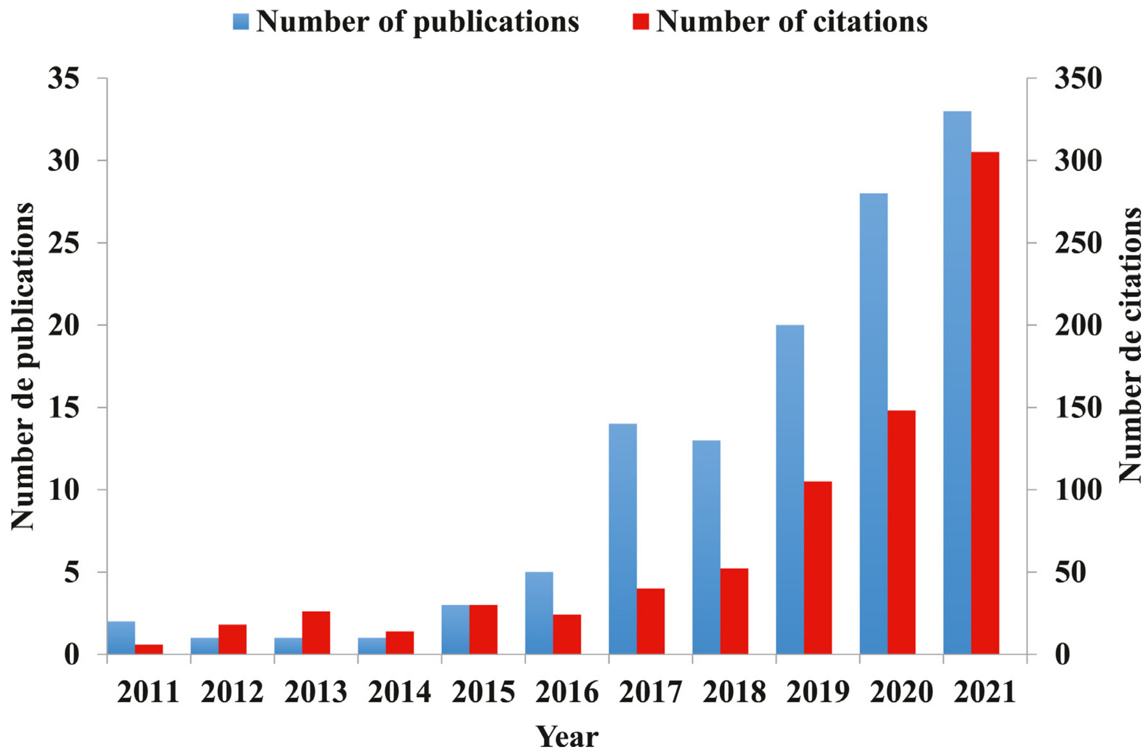

Fig. 1. Number of publications and citations including the use of Industry 4.0 in the food packaging in the last decade. Data were obtained from Scopus database in April 2022. Research criteria: Fourth industrial revolution OR Industry 4.0 AND Packaging.

and more people are concerned about their diet. Thus, an increasing number of consumers are looking for products that promote health and well-being (Wansink and Chandon, 2014).

Different food companies are in fierce competition with each other in order to win a large share of the market. In this process, the packaging is a formidable weapon serving as a vehicle for communication between customers and the companies. Changing packaging designs, adding information to labels, and even changing brand names are common tactics used to drive health-conscious consumers to buy products (S.A. Siddiqui et al., 2022b). Moreover, during this era of the fourth industrial revolution (called Industry 4.0), the development of packaging has experienced a massive boost due to digital innovations and emerging technologies that have accompanied this revolution. Therefore, it is no wonder that the number of publications and citations reporting on Industry 4.0 and packaging has increased significantly in the last decade (**Fig. 1**). Industry 4.0 has gained momentum in recent years, offering a wide range of digital and innovative technologies such as artificial intelligence, big data, smart sensors, Internet of Things, blockchain, and robotics, among others (Hassoun et al., 2022, 2022). Recently, the concept of Industry 4.0 was discussed from the packaging perspective, highlighting the numerous opportunities enabled by the digital automation and intelligentization of packaging to reach Packaging 4.0 (Sadeghi et al., 2022).

Packaging is one of the most powerful tools in the food industry because, in addition to its traditional role, it acts as a medium of communication and branding. According to Robertson (2012), packaging performs four functions, i.e., containment, protection, communication, and convenience. Nowadays, with consumers often looking for a statement on product packaging that aligns with their overall health and well-being goals, packaging design is an important factor when consumers are looking for healthy food. As a marketing tool, the packaging itself can promote healthier lifestyles and change consumption habits (Bou-Mitri et al., 2021; Küster et al., 2019; Vila-Lopez and Küster-Boluda, 2021). Food packaging, in particular, can help consumers visually categorize food into categories such as “healthy” and “unhealthy” (Karnal et al., 2016).

In 2019, the global food packaging market was valued at over $300 billion and is expected to grow at an annual rate of 5.2%. The paper-based part accounted for 31.9% of the total and dominated as a biodegradable material, while about 40% of plastic polymers have been used in the packaging industry in 2015, generating an urge amount of plastic waste worldwide (Groh et al., 2018; Pimentel Pincelli et al., 2021). Unfortunately, plastic food packaging is expected to grow rapidly globally due to superior performance and lower prices. It is expected that in the foreseeable future (2025–2030), the demand for plastic packaging materials will grow and this segment will occupy about 61.2% of the global market. This growth comes with environmental and pollution concerns (Motelica et al., 2020; Wohner et al., 2020). Furthermore, current consumer demands and needs are moving toward more natural, higher quality, more convenient and safer food, which poses a major challenge to the food industry. There is an increasing demand for food packaging that does not increase pollution and products that are efficiently manufactured through sustainable processes (Petkoska et al., 2021). These factors put pressure on the food industry to develop new antimicrobial packaging materials based primarily on natural, renewable resources or environmentally friendly biopolymers. Consequently, this has initiated an awareness and rise in research and industry focus on the development of sustainable, biodegradable, and edible materials that can improve food safety and increase food quality (Petkoska et al., 2021). In addition, this trend has also led to the use of functional foods, the development of novel foods industries, and the emergence of nanotechnologies in the food sector.

Regarding nanotechnology, it is the manipulation of nanomaterials applied for various purposes to promote human health through a novel and innovative approaches (Parisi et al., 2015). Nanostructures are basically prepared in the form of thin films, clusters, and wires. Nanoparticles are the simplest form and are the building blocks of nanostructures (Pathakoti et al., 2017; S.A. Siddiqui et al., 2022a). In the food sector,

Table 1
PICOS criteria for inclusion in the systematic review.

Acronym	Definition	Application of the criteria on the present study
P	Population	Consumers of food products, regardless of their gender and age
I	Intervention	New trends in food consumption, especially nanopackaging
C	Comparators	n.a.
O	Outcomes	Consumer social and psychological factors toward new trends in food consumption
S	Study design	Focus group discussion, interview, survey, or multi-group quantitative analyses

nanotechnology plays an important role in two areas: food additives and food packaging. There are a series of reports describing the application of nanotechnology in the food sector to improve food safety, extend shelf life, improve processing and improve diet quality.

The insertion of nanomaterials in packaging polymers is known as nanopackaging. Various nanomaterials are introduced as functional additives for food packaging, such as nano titanium dioxide, titanium nitride nanoparticles, silver nanoparticles, nanoclay, and nano-zinc oxide (Tager, 2014; Pal, 2017). For instance, few metal and metal oxide nanoparticles, namely iron, silver, zinc oxide, carbon, magnesium oxide, titanium oxide and silica nanoparticles, are widely used as antibacterial agents and under certain conditions used as a food ingredient (He et al., 2019; Blinov et al., 2021). In addition to antibacterial properties, nanomaterials can be used to detect food spoilage through nanosensors (Pathakoti et al., 2017). Nanosensors in packaging are used for tracking the condition of containers and products. According to Pal (2017), they can detect gas in food when it spoils and packaging changes color. Many types of smart sensors can be incorporated into food packaging in order to model freshness, determine the safety and quality of the packed foods (Franceschelli et al., 2021; Oveissi et al., 2022).

In view of the rapid industrial development of the food industry, motivation factors for consumer toward new trend in food consumption is also a crucial issue to discover. With the use of nanotechnology in the packaging industry, a new direction is developing - the production of biologically active packaging. This type of packaging includes antimicrobial packaging materials that suppress undesirable microbiological effects on bio-raw materials and the finished product; active packaging materials that timely warn of potential sources of spoilage, capable of eliminating and preventing undesirable changes occurring in the product; and containers and packaging materials that have an active influence on the biochemical and biotechnological processes of converting food raw materials into a product (Nile et al., 2020; Zhou et al., 2021; Kim et al., 2020). In recent years, there have been developments in the use of biodegradable materials for food packaging (Nilsen-Nygaard et al., 2021). At the same time, motivation factors for consumers toward new trends in the food industry, especially packaging, are also crucial issues to discover. Therefore, it appears important to assess consumer behavior toward nanopackaging, a gradually increasing new food trend. This present systematic review brings clarity to the context by collating and reviewing papers published in the last decade (2011–2022), that is the period of Industry 4.0, dealing with consumer social and psychological factors toward nanopackaging.

Methodology

The review covered scientific articles on consumer behavior or perspectives toward new trends in food consumption, especially nanopackaging. We applied the following initial inclusion requirement by following population, intervention, comparators, outcomes, and study design (PICOS) protocols as follows: (1) articles have been published after peer-reviewed; (2) article reporting on food nanopackaging; (3) letters to the editor, editorials, research pieces, conference abstracts, notes, papers presented at congresses, books, and thesis were not included; and (4) being written consistently in English. Furthermore, only articles published in the last decade (2011 to 2022) were retrieved. Inclusion criteria based on PICOS was described in Table 1.

Several keywords were chosen in order to search articles in reputable and authoritative research databases, i.e., Scopus “sciencedirect.com” and Web of Science “webofscience.com”. The appropriate literature was found using quotation marks and Boolean moderators (i.e., "AND" and "OR"). In each database search, the following keywords were used: “nanopackaging” OR “nanomaterial packaging” AND “consumer behavior”. We then looked through the reference lists of the selected papers in case there are missing and potentially relevant articles during the establishment of the dataset. Besides the year, only research articles were selected. With regard to social or psychological motivation factors for consumers toward new trends in food consumption, the review has two inclusion criteria to polish the data search. First, articles are more focusing on social or psychological motivation and new trends in food consumption. Second, these articles used focus group discussion, interview, survey, questionnaire or multi-group quantitative analyses like Structural Equation Modeling (SEM), Confirmatory Factor Analysis (CFA), Discrete Choice Experiment (DCE), Partial Least Square (PLS), Ward’s Method and Squared Euclidean Distance, Fuzzy Delphi Method, and Choice Experiment Method. In total, 39 articles were selected and analyzed to overview consumer behavior toward nanopackaging or new trends in food consumption.

Nanopackaging as a new trend in the food industry

Application and approach of nanotechnology in food packaging

The application of nanotechnology for food packaging development ensuring food safety and product quality has attracted attention and become a major impact on the food packaging industry. Innovation at the nanoscale and application of nanotechnology to polymer compounds opens up new opportunities for improvement not only for polymer properties but also toward a more efficient manufacturing cost (Mahmud et al., 2022). In fact, nanotechnology innovations have been developed to detect pathogenic bacteria, and used in active packaging, antimicrobial packaging, and as inhibitors of the formation of toxins (Donglu et al., 2016a, 2016b; Lin et al., 2015; Perumal et al., 2018). The application of nanotechnology also allows improvements to the physical and mechanical properties of packaging, including gas barriers, water absorption, strength, lightness, and decomposition. Additionally, the development of active and smart packaging that is equipped with nanoantimicrobials, nanosensors, and nanobarcodes can play several roles including i) maintaining quality (freshness) and food product safety, ii) assisting traceability, iii) monitor of product condition during distribution and storage, and iv) facilitate detection of contamination and damage before consumption.

The application of nanotechnology in food packaging for a variety of food products is overviewed in Table 2 and described in Fig. 2. According to the overview, most studies have been conducted on perishable food products, such as fruits, mushrooms, meats, and ready-to-eat foods. For example, the strawberries can be coated using clay-silica PE/POE/PA6 nanocomposites film with chitosan (Barikloo and Ahmadi, 2018) or packaged using pullulan-CMC electrospun nanofiber loading tea polyphenols (Shao et al., 2018). Both packaging methods are able to maintain the firmness and mechanical properties of the straw-

Table 2
Application of nanopackaging in various products.

Food products	Application nanotechnology in food packaging/coating	Effects on food products	Role of nano packaging in foods	Reference
Fruits and vegetables				
Apple (watercored)	Nano-titanium dioxide (nano-TiO_2) and litchi peel extract (LPE) were added to chitosan (CS) matrix	Maintaining the storage quality	Postharvest quality	(Liu et al., 2021)
Apple (fresh-cut)	Nano-coatings with α-tocopherol and xanthan gum	Reducing browning index Increasing shelf life of fresh-cut apples	Physicochemical characteristics	(Zambrano-Zaragoza et al., 2014)
Apricot	Nanochitosan emulsion coatings containing pomegranate peel extract	Inhibiting total psychrophilic Inhibiting bacterial count, yeast and mold count during storage	Antimicrobial effects	(Gull et al., 2021)
Avocado	Biopolymer coatings made of zein nanoparticles and ε-polylysine	Extending avocado shelf-life Reducing the severity of anthracnose in inoculated avocados	Antimicrobial activity	(Garcia et al., 2022)
Cantaloupe	Silver/titanium dioxide/chitosan adipate nanocomposite	Reducing *Escherichia coli* population by 6 logs after 24 h of incubation Maintaining quality and Extending shelf life	Antimicrobial activity	(Lin et al., 2015)
Carrot	Mahua oil-based polyurethane/chitosan/nano ZnO composite films	Improving anti-bacterial properties against gram positive and gram-negative bacteria Enhancing the shelf life	Antimicrobial activity	(Sarojini et al., 2019)
Cherry tomato	Bioactive packaging films prepared from starch/polyvinyl alcohol/silver nanoparticles/citric acid (starch/PVA/AgNPs/CA)	Maintaining freshness of fruits for at least 20 days of storage	Postharvest quality	(Ounkaew et al., 2021)
Cherry tomato	Polylactic acid/polyvinyl alcohol-quaternary ammonium chitosan double-layer films doped with novel antimicrobial agent CuO@ZIF-8 nanoparticles	Reducing growth of harmful microorganisms on the fruit surface	Antimicrobial activity	(Fu et al., 2022)
Cherry tomato	Konjac glucomannan based films reinforced with nanoparticles	Extending shelf life Reducing weight loss and firmness reduction	Postharvest quality	(Xiang et al., 2021)
Cherry tomato and strawberry	Locust bean gum (LBG)/carboxy cellulose nanocrystal (C–CNC) film	Reducing weight loss rate Decreasing oxygen transmission rate Extending the shelf life	Postharvest quality and antioxidant capacity	(Li et al., 2021)
Cucumber	Nanoscale and microscale CeO_2 and CuO	Reducing cucumber fruit firmness Increasing fruit fresh weight	Postharvest quality	(Hong et al., 2016)
Eggplant (fresh-cut)	Microporous packaging and nano-chitosan coating	Improving gas environment in the packaging bag Reducing microbial count Extending shelf life by more than 6 days	Antioxidant and antimicrobial effects	(D. Wu et al., 2021)
Grape	Biodegradable chitosan/cellulose acetate phthalate/ZnO nano composite films	Increasing shelf life by nine days Inhibiting *S. aureus* and *E. coli*	Antioxidant capacity and antimicrobial activity	(Indumathi et al., 2019)
Grape	Cellulose-based antimicrobial films incorporated with ZnO nanopillars	Inactivating bacteria by mechanically damaging cell membrane Improving antimicrobial activities.	Antimicrobial growth	(Xie et al., 2022)
Grape and strawberry	Pullulan/polyvinyl alcohol (PUL/PVA) nanofibers incorporated with thymol-loaded porphyrin metal-organic framework nanoparticles	Synergistic antibacterial activities against E. coli (~99%) and S. aureus (~98%) under light irradiation	Antimicrobial activity	(Min et al., 2021)
Green pepper	Polylactic acid/TiO_2/GO nano-fibrous films	Maintain the sensory quality Delaying the rate of spoilage Prolonging preservation period	Sensory properties and antimicrobial effects	(Dong et al., 2021)
Guava	Active edible coating of alginate and chitosan add ZnO nanoparticles	Extending guava shelf life up to 12 days	Postharvest quality	(Arroyo et al., 2020)
Jujube	Abscisic acid (ABA) and chitosan/nano-silica/sodium alginate composite film	Decreasing polyphenol oxidase (PPO) and peroxidase (POD) activities	Sensory properties and quality of postharvest	(Kou et al., 2019)
Jujube	Chitosan film with nano-silicon dioxide	Improving activities of scavenger antioxidant enzymes (i.e., superoxide dismutase, peroxidase, and catalase) Preserving total flavonoid	Antioxidant capacity and physicochemical characteristics	(Yu et al., 2012)
Longan	Chitosan/nano-silica coating	Reducing peroxidase activity Extending shelf life, Reducing browning index, Maintaining weight loss Inhibiting an increase of malondialdehyde amount and polyphenol oxidase activity	Postharvest quality and antioxidant capacity	(Shi et al., 2013)
Longan and banana	Waste fish scale-derived gelatin and chitosan into edible nanocomposite film	Extending postharvest storage period Improving antibacterial and mechanical properties of the film	Antimicrobial activity	(Fu et al., 2021)

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Table 2 (*continued*)

Food products	Application nanotechnology in food packaging/coating	Effects on food products	Role of nano packaging in foods	Reference
Loquat	Nano-SiO_2 packing	Inhibiting decay and internal browning indexes in both cultivars. Improvement of antioxidant capacity	Postharvest quality and antioxidant capacity	(Wang et al., 2020)
Loquat	Chitosan/nano-silica coating	Enhancing chilling tolerance and Providing a longer storage life	Postharvest quality and antioxidant capacity	(Song et al., 2016)
Mango	Bionanocomposite films enhanced with the addition of cellulose nanocristals to the Mt-PVA matrix	Extending shelf life until 19 ± 2 days Maintaining phenol, flavonoid content and DPPH antioxidant activity), Reducing mass loss, Increased CO_2 and low O_2 level.	Postharvest quality and antioxidant capacity	(Perumal et al., 2018)
Mango	Chitosan/Nano-TiO_2 composite coatings	Maintaining the quality Maintain the nutrient	Postharvest quality and physicochemical characteristics	(Xing et al., 2020)
Mango	Edible chitosan/zein-cinnamaldehyde nano-cellulose composite film	Maintaining mango postharvest quality and activated stress response.	Postharvest quality	(Xiao et al., 2021)
Mango	PLA nanocomposite films containing bergamot essential oil, TiO_2 nanoparticles, and Ag nanoparticles	Maintaining firmness, color, and vitamin C Inhibiting on microorganism growth Increasing shelf-life up to 15 days	Antimicrobial activity, and physicochemical characteristics	(Chi et al., 2019)
Orange	Cinnamaldehyde, eugenol and carvacrol nanoemulsion	Increasing antifungal effect on *Penicillium digitatum* Extending shelf life of oranges after harvest	Antimicrobial activity	(Yang et al., 2021)
Orange	Carnauba wax-nanoclay emulsion coatings	Enhancing fruit sensory/nutritional quality Reducing weight loss over storage	Postharvest quality	(Motamedi et al., 2018)
Orange (fresh-cut)	Nano-zinc oxide combined with pressurized argon treatment	Reducing mass loss Increasing soluble solids Reducing titratable acid and ascorbic acid contents Effectively inhibiting the growth of total aerobic bacteria and fungi	Postharvest quality and antimicrobial effects	(D. Wu et al., 2021)
Peach	Nano-ZnO-based low-density polyethene (NZLDPE)-packaging	Maintaining of cell wall structure and the degradation of the calcium-pectate gel Alleviating chilling injury and therefore Maintaining good quality during chilling stress.	Postharvest quality	(Li et al., 2017)
Peach	Glucose oxidase immobilized on ZnO nanoparticles	Extending shelf Life Maintaining weight	Postharvest quality	(Batool et al., 2022)
Pineapple (fresh-cut)	Curcumin loaded iron functionalized biopolymeric nanofibre reinforced edible nanocoatings	Showing anti-cancer activity by disrupting the cell membrane of HeLa (cervical cancer) cells Improving shelf life	Health concern	(Ghosh et al., 2021)
Pomegranate (ready-to-use)	Nano-ZnO/carboxymethyl cellulose-based active coating	Reducing microbial load and growth on aril surface Reducing weight loss and Maintaining overall quality of pomegranate arils	Postharvest quality and antimicrobial activity	(Koushesh Saba and Amini, 2017)
Raspberry	Nanocomposite films incorporated with cellulose nanocrystals and fruit peel extracts	Enhancing the antioxidant activities Extending the storage period of raspberries	Antioxidant capacity	(Kang et al., 2021)
Roasted peanuts	Guar gum/carboxymethyl cellulose based antioxidant film incorporated with halloysite nanotubes and litchi shell waste extract	Maintaining oxidative stability in roasted peanuts. Effectively increasing antioxidant activity for high lipid-containing food	Antioxidant capacity	(Deshmukh et al., 2022)
Strawberry	Nano-ZnO coatings	Maintaining bioactive constituents and fruit quality. Inhibiting total aerobic bacteria	Microbial growth, bioactive content and postharvest quality	(Sogvar et al., 2016)
Strawberry	Clay-silica PE/POE/PA6 nanocomposites film with chitosan coating under atmosphere condition	Maintaining the qualitative and mechanical properties Improving the shelf life	Sensory attributes and physical properties	(Barikloo and Ahmadi, 2018)
Strawberry	Tea polyphenols loaded pullulan-CMC electrospun nanofiber	Decreasing weight loss Maintaining the firmness, Improving the quality during storage.	Postharvest quality	(Shao et al., 2018)
Strawberry	k-carrageenan/konjac glucomannan/TiO_2 nanocomposite film	Improving strawberry storage period Improving photocatalytic anti-fungal activity	Antimicrobial activity	(Duan et al., 2021)
Strawberry	Carboxymethyl cellulose/cellulose nanocrystals immobilized silver nanoparticles	Maintaining quality Extending shelf-life to 7 days	Postharvest quality	(He et al., 2021)
Sweet cherry	Nano-silica coating combined with pressurized Ar treatment	Reduction of oxidative damage by scavenging ROSs. Reduction of decay incidence and Maintaining quality.	Antioxidant defense system	(Meng et al., 2022)

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Table 2 (*continued*)

Food products	Application nanotechnology in food packaging/coating	Effects on food products	Role of nano packaging in foods	Reference
Tomato	Chitosan/PCL nanofibrous films developed by solution blow spinning to encapsulate thymol (THY)/2-hydroxypropyl-β-cyclodextrin (HPβCD) inclusion	Improving antifungal activity in vitro and in vivo	Antimicrobial effects	(Shen et al., 2022)
Tomato	Edible nanolaminate coatings with antimicrobial extract of Flourensiacernua	Extending the shelf-life of tomato Inhibiting microorganism growth Improving WVP and O_2 permeabilities Decreasing the weight loss of tomato	Postharvest quality and antimicrobial activity	(Salas-Méndez et al., 2019)
Tomato	Nanoreinforced biodegradable gelatin based active food packaging film	Improving antimicrobial activity and Reducing cytotoxicity against animal cells Enhancing shelf life	Antimicrobial activity	(Sooch and Mann, 2021)
Yam (fresh-cut)	Nano-$CaCO_3$-LDPE packaging	Inhibiting browning and maintaining quality	Sensory properties	(Luo et al., 2015)
Mushrooms				
Button mushrooms	Ozone fumigation combined with nano-film packaging	Delaying deterioration and aging process of mushrooms. Improving antioxidant capacity of mushrooms and Extending shelf life of mushrooms at 4 °C by 8–10 days	Antioxidant and antimicrobial effects	(L. Wang et al., 2021)
Button mushrooms	Nano-SiO_2/TiO_2 loaded Polyvinyl alcohol (PVA)packages	Effectively controlling O_2 and CO_2 atmosphere Maintaining pH, color, total phenolics, ascorbic acid and antimicrobial activity	Antioxidant and antimicrobial effects	(Cai et al., 2022)
Button mushrooms	konjac glucomannan/carrageenan/nano-SiO_2 coatings	Delaying effect of the UV light on food quality Extending storage time of mushrooms	Postharvest quality and antimicrobial activity	(R. Zhang et al., 2019)
Button mushroom	Citrus pectin aerogel fortified with cellulose nanofiber	Maintaining hardness, color, total phenol content, cell membrane integrity and total antioxidant capacity Extending freshness period to 5 days	Postharvest quality	(Wu et al., 2022)
Button mushrooms	Bioactive mesoporous nano-silica/potato starch films	Improving antimicrobial activity against molds Improving antimicrobial activity against the CNRMA 03.0371 strain and the FJ09 species commonly found in post-harvest	Antimicrobial activity	(R. Zhang et al., 2019)
Enoki mushrooms	Polyethylene (PE) packaging material that contained nano-Ag, nano-TiO_2, nano-SiO_2, and attapulgite	Improving effects on barrier property and antibacterial activity Extending shelf life to more than 14 days	Antimicrobial activity	(Donglu et al., 2016a)
Enoki mushrooms	Nanocomposite packaging material (Nano-PM)	Maintaining sensory characteristics Increasing shelf life and Preserving quality	Sensory attributes and postharvest quality	(Donglu et al., 2016b)
Shiitake mushroom	Alginate/nano-Ag coating	Reducing mesophilic, pseudomonas, yeasts and molds counts Maintaining tissue firmness and inhibited browning Expanding shelf life and Improving preservation quality	Antimicrobial activity, postharvest quality and physicochemical characteristics	(Jiang et al., 2013)
Fish				
Fish meat	Grape seed oil-loaded nanofibers	Increasing antimicrobial effect	Antimicrobial activity	(Ceylan et al., 2021)
Red sea bream fillet	Edible composite film based on chitosan nanoparticles	Delaying lipid oxidation and proteolysis Improving physical properties	Antioxidant capacity and physical characteristics	(Zhao et al., 2022)
Sardine fillet	Nano-chitosan coatings incorporating with free /nano-encapsulated cumin (Cuminum cyminum L.) essential oil	Reducing lipid oxidation, microbial growth, Improving sensory attributes	Antioxidant capacity and sensory attributes	(Homayonpour et al., 2021)
Beef				
Chilled beef	Curdlan/nanocellulose blended film	Reducing microbial growth and Extending shelf life to 12 days	Antimicrobial activity	(Qian et al., 2021)
Fresh beef	Flexible chitosan-nanoZnO antimicrobial pouches	Increasing action against microbes in raw meat Extending the shelf life of raw meat	Antimicrobial activity	(Rahman et al., 2017)
Fresh beef and fermented sausage	LLDPE based food packaging incorporated with nanoclays grafted with bioactive compounds	Maintaining fresh meat color up to 4 days Increasing bacteriostatic/bactericidal effect on *E. coli* O157:H7	Antimicrobial activity	(Tornuk et al., 2015)
Minced beef	Chitosan monoterpene nanoparticles	Increasing in vivo antimicrobial and antioxidant property	Antimicrobial activity	(Badawy et al., 2020)
Minced beef	Halochromic freshness/spoilage nanocellulose label	Estimating visual shelf life of meat Differentiating fresh, medium fresh and spoiled minced meat Revealing pH sensing label for visual sensitivity to pH changes (2–11)	Freshness indicator	(Taherkhani et al., 2020)
Refrigerated beef	Eco-friendly active packaging consisting of nanostructured biopolymer matrix reinforced with TiO2 and essential oil	Improving antibacterial and antioxidant activity Increasing shelf life to double	Antimicrobial activity and antioxidant capacity	(Alizadeh-Sani et al., 2020)
Vacuum-packaged beef	Bacterial cellulose nanocrystal coating and nicin-loaded bacterial cellulose nanocrystal coating	Increasing microbial growth	Antimicrobial activity	(Gedarawatte et al., 2022)

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Table 2 (*continued*)

Food products	Application nanotechnology in food packaging/coating	Effects on food products	Role of nano packaging in foods	Reference
Pork				
Pork	pH sensitive film based on starch/carbon nano dots incorporating anthocyanin	Increasing mechanical strength, water barrier and antioxidant activity Monitoring spoilage of pork Employing anthocyanin as pH indicator	Antimicrobial activity and pH indicator	
Pork	Nano-encapsulated omega-3 fatty acids	Improving nutritional profile of meat	Nutritional quality	(Ojha et al., 2017)
Pork	Glycyrrhiza polysaccharide nanofibers loaded with tea tree essential oil/ gliadin nanoparticles	Increasing inhibitory effect on *S. typhimurium* Delaying the lipid oxidation	Antimicrobial activity and antioxidant capacity	(Cai et al., 2021)
Pork	Nanoemulsion-based active coatings with composite mixture of star anise essential oil, polylysine, and nisin	Improving quality and shelf life Improved sensory acceptability	Sensory attributes	(Liu et al., 2020)
Ready-to-cook pork chops	Chitosan coatings incorporated with free or nano-encapsulated Paulownia Tomentosa essential oil	Improving effects on meat quality Reducing lipid oxidation, microbial growth, and Improving sensory attributes	Antimicrobial activity, antioxidant capacity and sensory attributes	(B.Y. Zhang et al., 2019)
Refrigerated pork	Chitosan nanoemulsions with thymol or thyme essential oil on volatile compounds	Inhibiting lipid oxidation and microbial growth in pork Extending shelf-life of fresh pork	Antimicrobial activity	(Wang et al., 2022)
Other red meat				
Lamb meat	Chitosan coatings incorporating with free or nano-encapsulated Satureja plant essential oil	Reducing lipid oxidation, microbial growth, and improved sensory attributes Improving effects on quality attributes of meat	Antimicrobial activity and antioxidant capacity	(Pabast et al., 2018)
Lamb meat	pH-responsive color indicator films based on methylcellulose/chitosan nanofiber and barberry anthocyanins	Improving antioxidant activity Exhibiting as smart indicator for real-time monitoring freshness of meat and seafood products	Antioxidant capacity and freshness indicator	(Alizadeh-Sani et al., 2021)
Lamb meat	Whey protein isolate/cellulose nanofibre/TiO2 nanoparticle/rosemary essential oil nanocomposite film	Inhibiting growth of spoilage and pathogenic bacteria Improving organoleptic properties Increasing shelf life	Antimicrobial activity and sensory attributes	(Alizadeh-Sani et al., 2017)
Refrigerated lamb loin	Safflower oil nanoemulsion and cumin essential oil combined with oxygen absorber packaging	Enhancing antimicrobial and antioxidant activity Enhancing quality parameters Extended shelf life	Antimicrobial activity and antioxidant capacity	(Hasani-Javanmardi et al., 2021)
Refrigerated minced camel meat	Nanoemulsion-based basil seed gum edible film containing resveratrol and clove essential oil	Improving in vitro antioxidant activities Improving oxidative stability and sensory properties	Sensory attributes and antioxidant activities	(Ansarian et al., 2022)
Poultry				
Chicken breast meat	Nanocomposite active packaging based on chitosan biopolymer loaded with nano-liposomal essential oi	Improving antimicrobial activity on refrigerated chicken meat. Improving chemical properties	Antimicrobial activity and physicochemical characteristics	(Kamkar et al., 2021)
Chicken breast meat	Nanocomposite packaging containing different proportions of ZnO and Ag	Improving antimicrobial effect and Delaying lipid oxidation Increasing storage time	Antimicrobial activity and antioxidant capacity	(Panea et al., 2014)
Chicken breast meat	Gelatin-nanochitosan films incorporated with *Zataria multiflora* essential oil	Reducing growth of spoilage bacteria in chicken meat Delaying lipid oxidation	Antimicrobial activity and antioxidant capacity	(Hematizad et al., 2021)
Chicken fillet	Eco-environmental nano-emulsified active coated packaging material	Extending shelflife time Increasing sensory score of consumer acceptance	Consumer acceptance	(Ibrahim and El-Khawas, 2019)
Chicken thigh meat	Nano structure cellulose-polypyrrole-ZnO film	Improving antimicrobial and antioxidant activity. Estimating storage time and storage temperature of chicken thigh as intelligent packaging	Antimicrobial activity, antioxidant capacity and freshness indicator	(Pirsa and Shamusi, 2019)
Chicken thigh meat	ZnO nanoparticles combined radio frequency pasteurization	Retaining tissue microstructure Improving water retention Reducing quality degradation	Physicochemical characteristics	(Xu et al., 2020)
Ready-to-eat chicken meat	Tapioca starch active nanocomposite films	Inhibiting growth of *Listeria monocytogenes* during the storage	Antimicrobial activity	(Xu et al., 2018)
Ready-to-eat chicken meat	Cold atmospheric plasma and linalool nanoemulsions	Reducing foodborne pathogens Reducing lipid oxidation levels	Antimicrobial activity and antioxidant capacity	(González-González et al., 2021)
Ready-to-eat poultry meat	Zinc oxide nanoparticles loaded active packaging	Inhibiting growth of pathogens in-vitro	Antimicrobial activity	(Akbar and Anal, 2014)
Quail meat	Composite film based on potato starch/apple peel pectin/ZrO2 nanoparticles/ microencapsulated *Zataria multiflora* essential oil	Increasing shelf life of the meat	Antimicrobial activity	(Sani et al., 2021)

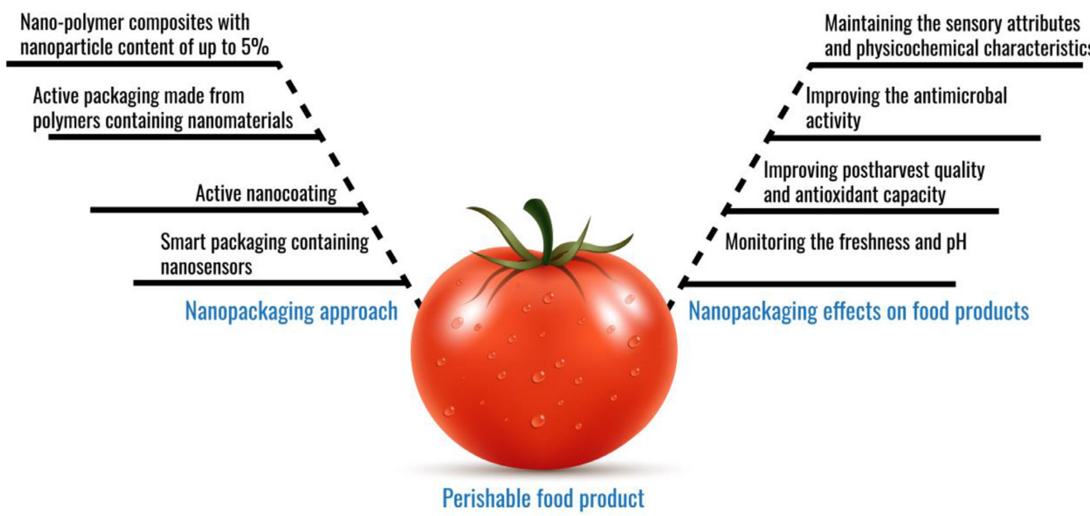

Fig. 2. Review of nanopackaging approach and effects on variety of food products.

berries and decrease weight loss as well as physical, biological and chemical damage during distribution. The effectiveness of nanopackaging is also shown in ready to eat food products, such as poultry meats (Akbar and Anal, 2014), pork chops (B.Y. Zhang et al., 2019), meat products (Liu et al., 2020), chicken meat (Xu et al., 2018), cheese (Gvozdenko et al., 2022) where nanocomposite films can improve the sensory acceptability and attributes, reduce lipid oxidation, and inhibit spoilage and pathogenic bacteria. The application of nanopackaging on food products is expected to prolong the products' shelf life.

The application of nanopackaging in food products is implemented in different ways, depending on the physical, chemical, and biological characteristics of foods. Fig. 2 shows the implementation of nanopackaging in food products according to this review study. The incorporation of nanomaterials into plastic polymers has encouraged the development of innovative food packaging materials, which can generally be classified into four categories. These categories are (1) nanopolymer composites with nanoparticle content of up to 5% producing better characteristics in terms of flexibility, durability, stability to temperature and/or humidity, and gas transfer/migration; (2) active packaging made from polymers containing nanomaterials with strong antimicrobial activity; (3) active nanocoating to maintain the cleanliness of the surface of the material or food contact and hydrophobic nanocoating; and (4) smart packaging containing nanosensors to monitor and report food conditions and/or atmospheric conditions inside the packaging, and nanobarcodes to determine food authenticity/traceability (da Costa et al., 2020; Donglu et al., 2016a; Duncan, 2011; Ghosh et al., 2021; Kamkar et al., 2021). Aytac et al. (2020) stated that future packaging trends should focus on the development of biodegradable materials from biopolymers and nature-derived antimicrobials, enhancing food safety, and quality. The biodegradable nanopackaging that can be applied in horticultural products includes nanoedible coatings, nanoedible films, and nanoantimicrobials (Ashfaq et al., 2022; Duncan, 2011).

Edible coatings can be applied to a food product by wrapping, dipping, brushing, or spraying to provide a selective barrier against the movement of gasses, moisture, and dissolved materials as well as protection against mechanical damage (Fig. 3) (Jovanović et al., 2021; Yousuf et al., 2018). The edible film is a thin layer made of edible material, formed to coat food or attached between food components and film, which functions as a barrier to mass transfer (e.g., moisture, oxygen, light, lipids, and solutes) and/or as an additive carrier to improve the handling of food. Ghosh et al. (2021) showed that nanocoating can be used to coat fruit, such as fresh-cut pineapples, to prevent weight loss. Biodegradable bio-nanocomposites made from natural biopolymers such as starch and protein have advantages as food packaging materials due to their organoleptic characteristics, such as good appearance, smell and taste (Lemos Machado Abreu et al., 2017). The biodegradable packaging (nanoedible coating and nanoedible film) can be modified by adding nano-based antimicrobial substances such as nano-ZnO (zinc oxide) (Batool et al., 2022; Helmiyati et al., 2021; Sarojini et al., 2019; Saba and Amini, 2017), nano-TiO_2 (titanium dioxide) (Alizadeh-Sani et al., 2020; Chi et al., 2019; Xing et al., 2020), and nano-Ag (silver) (Deus et al., 2017; Lin et al., 2015; Ounkaew et al., 2021; L. Wang et al., 2021). However, nanoparticle-based studies are more focused on nano-ZnO functioning as a zinc supplement, because the health effects of nano-Ag and nano-TiO_2 in food packaging are still being debated (Istiqola and Syafiuddin, 2020).

Roles of nanopackaging for food safety and quality of food products

Future packaging systems should be able to close the small pores in the packaging and have a good response to the environment such as changes in temperature, air and humidity (Bahmid et al., 2021; Viscusi et al., 2021). The use of nanopackaging is expected to increase the added value of food products with broad potential benefits. Some of these benefits include controlling the ripening process of fruit, maintaining the freshness and safety of meat, detecting food contaminants/pathogens, and detection of food expiration (Ibrahim and El-Khawas, 2019; Kamkar et al., 2021; Li et al., 2017; Nagdalian et al., 2021). For example, Batool et al. (2022) reported an enhancement of the postharvest shelf life of peach using zinc oxide nanoparticles treated with glucose oxidase. According to the review in Table 1, the main roles of nanopackaging in food safety and quality of products can be divided into (1) preventing antimicrobial activity; (2) improving barrier and mechanical properties; and (3) maintaining products' antioxidant capacity and postharvest quality.

The antimicrobial activity of nanoparticles is related to several mechanisms. Nanoparticles can directly interact with microbial cells by interfering with electron transfer trans membranes, disrupting/penetrating cell membranes, oxidizing cell components, or producing secondary products (e.g., reactive oxygen species) or dissolved heavy metal ions that cause cell damage (Meng et al., 2022). Nanoparticles can be utilized to extend the shelf life of different types of food products that are easily damaged by microbial activity such as meat and its processed products, minimally processed foods, vegetables, etc. (Fig. 4**).**

The incorporation of nanoparticles such as ZnO, Ag, TiO_2, TiN, and SiO_2 has been proven to contribute to the improvement of barrier (e.g., gas, moisture, and stains) and mechanical (e.g., flexibility, durability, and stability to temperature and moisture) properties (Cai et al., 2022;

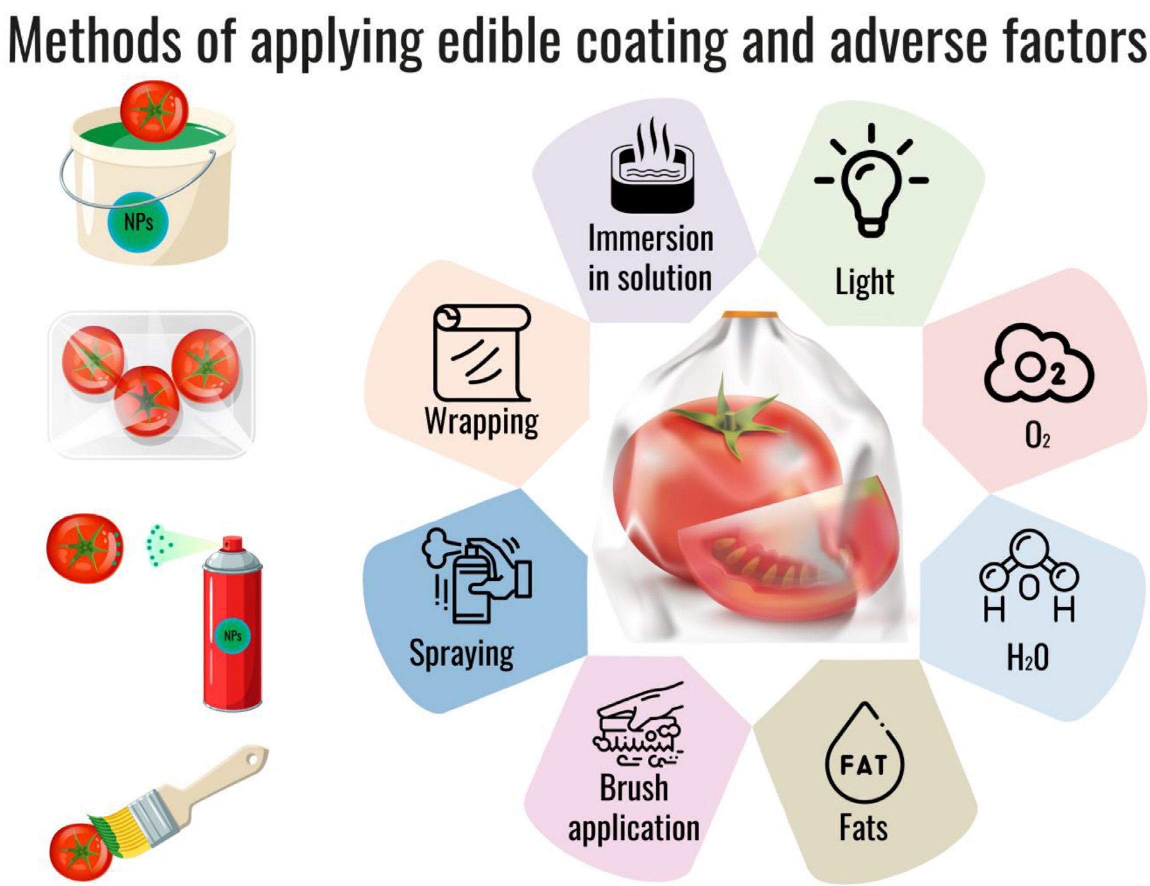

Fig. 3. Methods of applying edible coating and adverse factors.

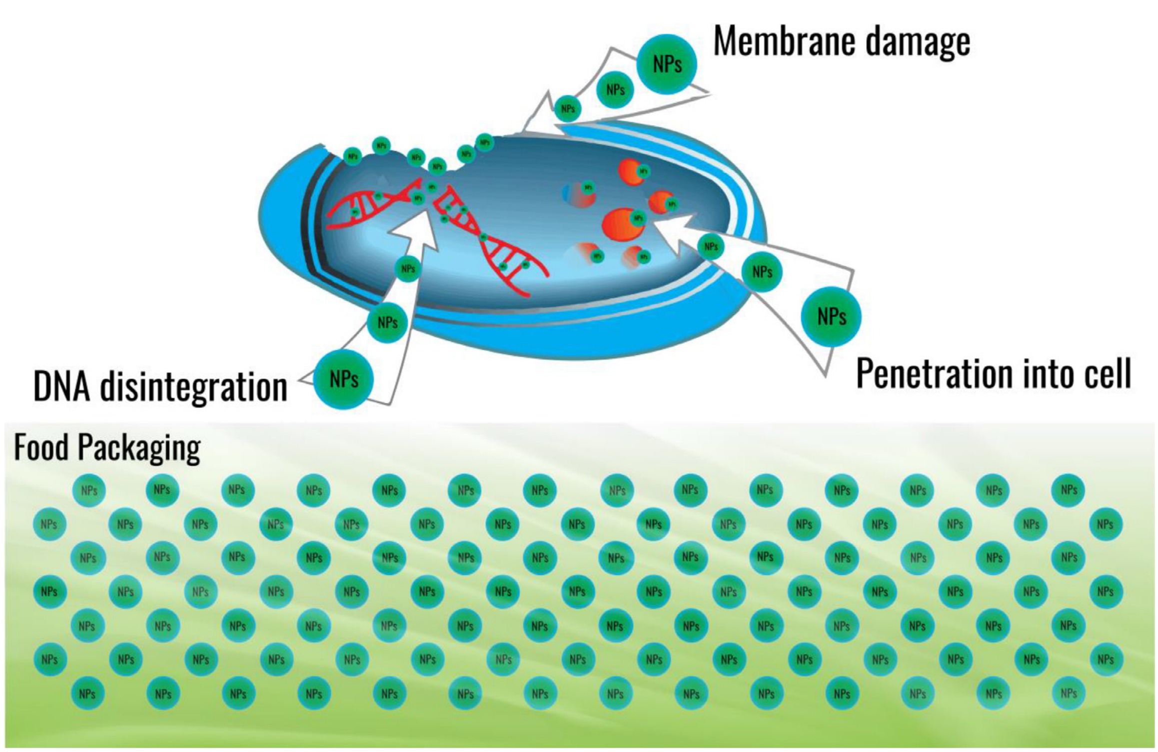

Fig. 4. Mechanisms of nanoparticles' effect on bacterial cell.

Helmiyati et al., 2021; Wang et al., 2020; Xing et al., 2020). The mechanism for improving the mechanical properties is related to the interfacial interaction between nanoparticles (filler) and the matrix and the presence of nanoparticles in the polymer film matrix inducing the transfer of water vapor and gasses.

Nanoparticles stabilized with polymers used in food packaging materials improve the antioxidant capacity and postharvest quality of the product. Antioxidant activities involve several mechanisms. In mushrooms, fruits and vegetables, antioxidant capacity from nanoparticles plays a role in alleviating lipid peroxidation and delaying senescence (Donglu et al., 2016b). Nanocoating is able to reduce the weight loss in fruit by splitting the decomposition of the product composed of the polymer (Li et al., 2021).

Regulations for nanotechnology in food packaging

Although the utilization of nanomaterials in the food industry is flourishing, the specific regulation concerning their usage is not well established. Kuswandi (2017) suggested that there are at least three regulations to impose the safe implementation or best practice of nanotechnology in the food industry, i.e., food regulation, health regulation, and environmental regulation. In the United States, in 2014, Food and Drug Administration (FDA) issued several nanotechnology guidance documents, necessitating manufacturers to conduct a thorough toxicology profiling of the nanomaterial used in food products. Thus, it is prohibited to sell untested products containing nanomaterials. For instance, the United States Environmental Protection Agency (EPA) withdrew the circulation of food containers containing nanosilver in 2014 since the products had not been tested or registered with the EPA. As a result, some other food container companies also stopped selling their products due to the unverified claims attached to the products (Bumbudsanpharoke and Ko, 2015).

In the European Union (EU), food products containing nanomaterials are considered novel, thus, they are covered by the novel food regulation (EU Regulation No 1169/2011). In this circumstance, particular provisions are applied from 2018 onwards for the safety assessment and authorization of the food products containing nanomaterials. Additionally, as per EU Regulation No 1169/2011, all nanomaterials used in a food product must be written in the list of ingredients. Moreover, it is required that the nanomaterials used in food contact materials be approved and tested for the potential risk associated with them (EU Regulation No 10/2011) (Rauscher et al., 2017). According to Rai et al. (2019), to date, regulatory authorities around the globe are continuously monitoring the development of nanotechnology in food packaging. Furthermore, the authors argue that there is a need of comprehensive analysis and discussion about the regulatory needs for nanomaterials.

Consumer perspective on food products packaged by nanopackaging

A number of issues related to the safety of nanotechnology products remain a major concern. For example, potential health effects of nano-Ag and nano-TiO_2 were reported in food packaging (Istiqola and Syafiuddin, 2020). However, the impact of increased nano-Ag usage on human health and the environment is still unknown. Public perception of food products with nanotechnology involves nano-inorganic materials being introduced into food products and eventually entering the human body (Ghosh et al., 2021). According to Capon et al. (2015), based on their characteristics, the food safety risks of nanotechnology products can be divided into three categories, namely (1) low risk, where food products/food packaging contain natural nanoparticles/nanostructures that can be digested and are not bio-persistent (accumulates in the body or the environment), (2) moderate risk, where food products/food packaging contain active ingredients/food additives coated with a nano delivery system that can penetrate the digestive tract and increase absorption and bioavailability, and (3) high risk, where the food product/food packaging contains insoluble, undigested and potentially bio-persistent nanoparticles, such as metal nanoparticles and metal oxides. In this high risk group, consumers or the environment are very potentially exposed to nanoparticles whose toxicity properties are not yet widely known (Ashfaq et al., 2022). Therefore, it is vital to remember that while assessing the health effects of a novel food contact ingredient, toxicity data must be balanced against the ease with which the substance may be released from packing materials into diverse foods. Another key aspect of consumer behavior is less amount of food waste generated from food packaged by nanopackaging. Zhang et al. (2019) analyzed the life cycles of nanopackaging and packaged foods by characterizing the correlation between food shelf life and waste. From 628 responses, the results showed that nanopackaging beneficially affects the carbon footprint of food preservation due to the 1–3 extension shelf life of food products. The result obtained in this study may become the main trend for producers of food packaging materials in the near future.

To generalize represented studies, we created a scheme of consumer behavior models toward food nanopackaging (Fig. 5). Fig. 5 shows the factors that influence a purchase decision for a food product enhanced with nanopackaging. A distinction can be made between psychological, moderate variable and controllable variables. The interaction of these variables in turn leads to the consumer's attitude for or against nanopackaging and thus, in addition to subjective norms and a perceived control, to the consumer's behavior and ultimately to the purchase decision.

Social motivation factors for consumer toward nanopackaging

In a world that is developing rapidly, various inventions emerge as answers to various issues faced by humans, including food packaging innovation. The emergence of various smart packaging developments raises various new preferences for consumers through a combination of elements of product information, subjective norms, and perceived consumer behavior. With the increasing number of packaging products on the market, changes in lifestyle, and the rapid spread of trends toward food have directly affected consumers' attention to consuming packaged food. It is clear that packaging plays a considerable role in consumer behavior (Chu et al., 2021; Friedrich, 2020; Panda et al., 2021).

Consumer research is a crucial phase in the packaging design process, and food manufacturers can use their results to develop their marketing strategies. Food packaging is an effective marketing tool, the importance of which is reflected both in the functions performed and in the role in the decision-making process for purchase by consumers. It is worth remembering that the consumer's first contact with a product is made mainly through packaging. The characteristics of the packaging often determine the interest in the product. At the same time, the growing information role of nanopackaging is the result of many waves of abuse in the production and marketing of food and the frequent use of additives with unknown effects in the future. Product labeling is crucial to provide security and reliable information on the nutritional value of consumers (Wyrwa and Barska, 2017).

There are various factors that influence consumer behavior toward food consumption. Health motivation is the most significant factor in consumer behavior across a variety of foods due to the growing interest in healthy eating patterns in society (Profeta et al., 2021; Stancu et al., 2022). Meanwhile, consumer food preferences are complicated, involving not just health but also economic, social, and psychological factors. Consumer behavior studies, on the other hand, have tended to focus on health and economic considerations, while social and psychological elements have been infrequently addressed (Huang et al., 2020; Nafees et al., 2022). In fact, several consumer studies show that consumer behavior is based on attitudes, culture, and norms, which include habits, needs and experiences felt by consumers. All of these factors can play a role in consumer behavior towards the use of nanopackaging for the food industry because this approach is still relatively new to consumers. Thus, since it is difficult to encompass the social motivation

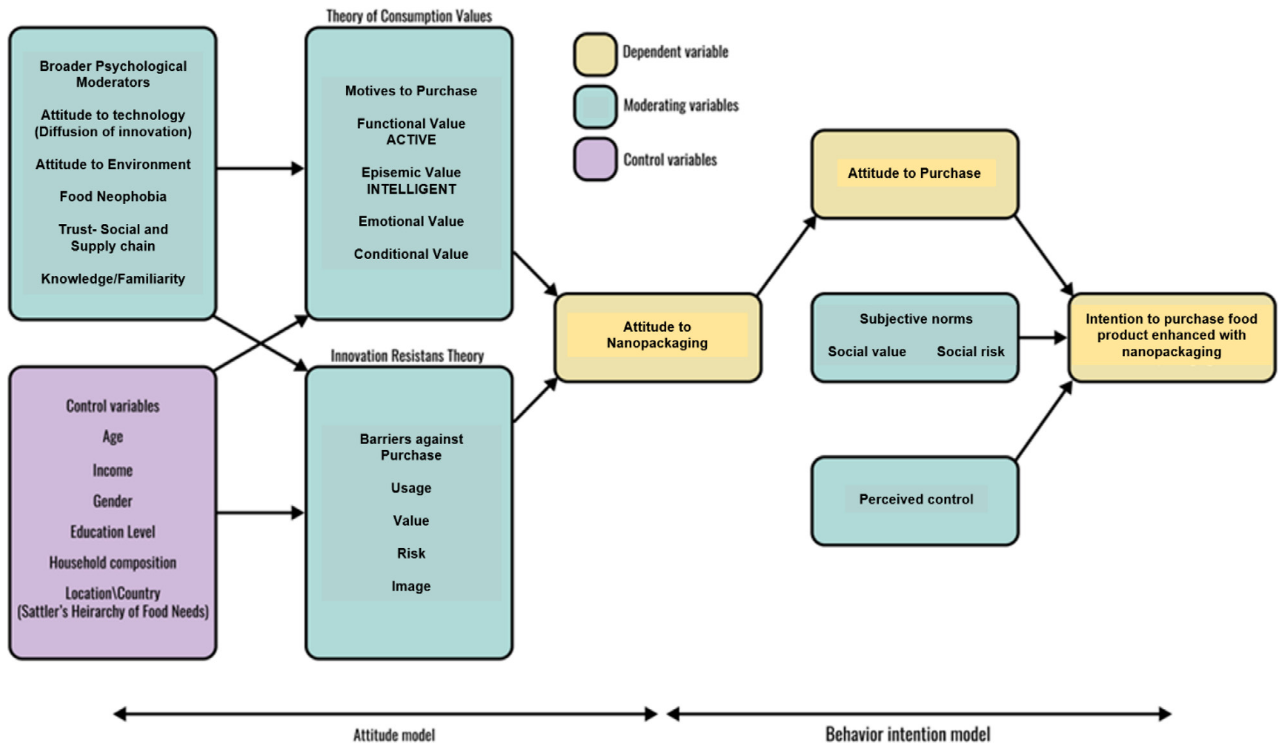

Fig. 5. Scheme of consumer behavior models toward food nanopackaging.

specifically toward nanopackaged foods, this review will also cater to social determinants of other types of products (Table 3).

Researchers have created a number of social-psychological models that may be used to analyze decision-making elements and processes, as well as to design interventions to shift target behaviors in more positive directions. The Theory of Planned Behavior is one of these models that has been widely used in forecasting consumer intents and behaviors in a variety of domains, including food choice. In a nutshell, the theory suggests that intention and perceived behavioral control determine people's conduct. Individual attitudes toward the conduct, perceived social pressure to execute the behavior or not (subjective norm), and perceived confidence in one's ability to perform the behavior all influence the individual's intention (Huang et al., 2020; Tønnesen and Grunert, 2021).

Chang et al. (2017) examined the effects of innovative features, consumer characteristics, and trust in authority on subjective perceptions (perceived trustworthiness and perceived benefit) as well as the social influence on attitudes toward nano-foods and trial willingness. Their results indicated that innovative characteristics (relative advantage, lack of observability, and novelty), consumer characteristics (perceived technology application), and social characteristics (trust in authority) affect perceived trustworthiness or perceived benefit. Social influence also had a direct effect on attitude toward nano-foods and trial willingness.

Nonetheless, Huang et al. (2020) explains that needs and habits have a significant impact on intentions. Consumer acceptance of the relatively new use of nanopackaging requires repeated mediation, which is accompanied by education to form habits by adjusting to consumer needs. The understanding of the benefits of nanopackaging on consumers needs to be increased that the use of nanopackaging aims to improve food quality and reduce the impact of plastic packaging on the environment. Soorani & Ahmadvand (2019b) also conducted an investigation of consumer food management behavior to reduce food waste that constructs, attitudes, experiences and norms can influence intentions to reduce food waste. This suggests that environmental impacts can be an area that can be exposed to promote the benefits of nanopackaging in the use of food packaging

Media behavior was a recent theme that appeared in previous studies. Today's consumers are the people who grew up in a digital era. Overall, it can be deduced that the majority of people's media activity and consumption is focused on the subject of food. Platforms for interaction have been developed by modern technology, and they are becoming increasingly significant in consumer behavior (Jacobsen et al., 2021). For example, Jacobsen et al. (2021) observed that consumers are increasingly engaging in online discussions with their peers regarding food choices and diets to share with their peers on social media platforms. For example, consumers can utilize interactive communication technologies to communicate with food companies about product issues or ideas. In another study, Närvänen et al. (2013) used social media to learn how people talk about convenient food on a daily basis. Social media may be used in product creation to discover consumer preferences and spot new trends in the convenience food industry. Data from social media sites are useful for gaining insight into consumer patterns, but they should be thoroughly scrutinized before being used. However, food behavior is thought to be taught rather than innate, and the development of eating behavior is influenced by a variety of external factors such as parenting, social influences, and the food environment.

Social motivation can directly influence consumers' choices of food product choices or the level of use of plastic and innovative food packaging. The necessity to reduce the utilization of plastic packages led to looking for new trends and innovations in food packaging technologies such as nanopackagings. For example, Wiefek et al. (2021) found that the influence of social norms, social conventions, and culture of consumerism on behaviors related to the use of plastic seems to be the strongest hurdle among all when it comes to reducing plastic packaging and a fundamental cultural change is needed. Although this is a challenge, retailers consider that the trend of sustainable consumption has a consequence and has a positive impact. It is found by Louis et al. (2021), that unpackaged products can be a strategic tool for retailers to strengthen interactions between customers and producers. This shows that creativity and the ability to see opportunities from the use of nanopackaging need to be emphasized by looking at aspects of consumer preferences for the use of nanopackaging in packaging.

Table 3
Social motivation factors influencing consumers' decision to consume food products.

Study	Methodology	Main Result	References
Identified personal and structural barriers that hinder a reduced plastic packaging consumption.	Focus group discussions	Fundamental changes in infrastructures and lifestyles, as well as cultural and economic transformation processes are needed to make zero-waste shopping the norm and unpackaged goods the most affordable and convenient option.	(Wiefek et al., 2021)
To get insight into the influence of attitudes, perceived social norms, abilities, and other psychological factors on pork consumption among young consumers in Denmark and Sweden.	Questionnaire surveys Multi-group structural equation modeling	Young Danish and Swedish consumers' intention to buy pork and consumption of pork were primarily influenced by attitudes and habit strength, while social norms and perceived abilities played a minor role.	(Tønnesen and Grunert, 2021)
To build and test a conceptual model surrounding the idea of a generous consumer – and what may lead a consumer to buy products affiliated with cause-related marketing	Confirmatory factor analysis using AMOS 26	Several pro-social consumer behaviors are predictors of cause-related purchasing intentions. Additionally, it is found that interpersonal generosity mediates other pro-social behaviors in determining consumer receptiveness to cause-related market exchanges.	(Rapert et al., 2021)
To assess which green nudges are most effective to increase consumer WTP for biobased packaging.	Survey with a discrete choice experiment (DCE) and between-subject design approach	The strongest effects are generated when the nudging strategy matches the characteristic of consumers' cognitive style	(Wensing et al., 2020)
To examine the effects of social-psychological factors in food consumption of rural residents in poor counties of Southwest China	Survey Structural equation modeling	Incorporation of perceived need and habit substantially increased the explanatory power of the TPB, but these factors only had significant direct effects on intention rather than behavior	(Huang et al., 2020)
Investigates the consequences for retailers and their stores of a new sustainable consumption trend—the purchase and consumption of bulk products	PLS-SEM Ward's method and squared Euclidean distance	Unpacked products are a strategic tool for retailers and their stores to create or strengthen the relationships established with their customers	(Louis et al., 2021)
To explore the relative perceptual profiles of organic food consumers who buy out of concern for their health and for the environment, respectively.	Survey	The primacy of health and environmental motives among urban Indian millennial organic food users, and show that those who buy organic food primarily for their health are pragmatic types mostly concerned about performance and utility, whereas, those who buy primarily to help the environment are social individuals mostly concerned about their appearance to others.	(Nafees et al., 2022)
To predict consumers' purchase intentions of wellbeing food, namely Yak-sun.	Questionnaires	All constructs including attitude, subjective norms, and perceived behavioral control were found to have made a significant contribution to the prediction of intention to purchase Yak-sun food among Korean consumers. Perceived behavioral control showed the strongest influence on the behavioral intention of purchasing Yak-sun food.	(Lim and An, 2021)
To investigate the consumer food management behavior in order to reduce food waste	Survey SEM	Intention to reduce household food waste is predictable by attitude, subjective norm and feelings of guilt constructs	(Soorani and Ahmadvand, 2019a)
To establish a phenomenological understanding of food enthusiasm and subsequently identify key behaviors to categorize customers effectively.	Interview	Distinctive groups whose behaviors vary significantly in explaining food enthusiasm.	(Moreo et al., 2022)
To develop a framework to assist packaging designers in integrating consumer preferences and environmental impact during their design procedures.	Survey	the trade-offs between the environmental and functional aspects, and the design option that seemed best in one respect did not always have the highest eco-efficiency. The framework can support packaging designers in selecting consumer-preferred options with low environmental impact.	(Yokokawa et al., 2021a)
To identify the consumer-centered attributes that influence consumer willingness-to-pay value for a sustainable consumption transition model	Fuzzy Delphi method and choice experiment method	Social concerns and waste minimization perspectives contribute the most to the sustainable consumption model in which the criteria such as consumers' sustainable issue interest, responsible waste disposal and health-based products play a major role in influencing consumer WTP	(Chen et al., 2021)
Exploring the consumers' behavior when purchasing food products, and the influence over such decisions of companies' social practices within their CSR.	Grounded Theory Interview	Consumers are sensitive to social abuse practices, but they face difficulties to access information in order to inform their decisions.	(Toussaint et al., 2021)

The strongest behavioral antecedents have been discovered to be social norms. According to empirical studies, presenting normative information encourages people to act in accordance with their peers. A person can identify with and belong to a group if they share the same values, beliefs, and actions as other members of that group (Louis et al., 2021). The individual will then act in accordance with the group's social standards in order to retain and strengthen their group identification. It was discovered by Nafees et al. (2022) that customers might utilize things like organic food to distinguish themselves from others, in this example as a statement to others that the consumer cares about the environment, and to form conclusions about other people's identities and social roles. When compared to other types of information, normative information was more effective in improving household conservation behavior (Wensing et al., 2020).

In addition, the pro-social model shows an influence on consumer food-buying behavior. For instance, Chen et al. (2021) depict sustainable problem interest, environmentally conscious consumers, and willingness to reuse products are the top three criteria for social concerns. The findings suggest that social concerns, waste minimization, and economic considerations are all valid factors in influencing customers' willingness to pay for the shift to sustainable consumption. Meanwhile, Toussaint et al. (2021) provides an analysis of the possible factors that influence the purchasing decision, and show that the average consumer is often not even aware of social issues along the value chain.

Design on packaging might also be affected by social norms. For example, Chu et al. (2021) discovered that recommending smaller serving amounts could trigger social norm processes. Consumption norms, which imply the "proper" amount to consume, are well-known as powerful predictors of intake. Besides that, Yokokawa et al. (2021) discovered that by altering the product design, packaging designers can impact consumer behavior. Designs that can impact knowledge and contexts are useful for routinized consumer behavior since the materials are interconnected with other factors. Tray packing, for example, is preferred by consumers who want to avoid dishwashing in their daily routines (social culture). On the other hand, packaging design can be used as marketing and promotion. This ability can change consumer perceptions of packaged products, by emphasizing product quality and the effectiveness of nanopackaging in improving the quality of packaged food. As a future consideration, the trade-off between environmental and functional aspects, and the design choice that seems best in one respect does not always have the highest eco-efficiency (Yokokawa et al., 2021). Therefore, an in-depth consumer study of the use of nanopackaging in food products on consumer habits and behavior becomes very necessary, which is based on environmental, food product quality and economic aspects.

Psychological motivation factors toward nanopackaging

Factors affecting consumer food choices

As a result of the growing consumer demand for natural products and the need to feed the increasing population on a global scale, traditional packaging is becoming less and less able to meet the functional requirements set before them. Innovative packaging, an emerging technology in the food packaging industry, includes both active and intelligent technologies. Nanomaterials are designed to increase product performance, superiority, and durability today. Due to nanomaterials' multifunctional properties, nanoproducts are a group of high-quality products that have recently become widespread. This situation also affects product prices. In some cases, it raises product prices and causes them to be perceived as more expensive than products in the same category. Many factors such as family, status, social norms, religious impositions, the education system applied throughout the country, and the management style constitute the people's perspective towards different areas. These factors also provide social communication in society, and the social communication structure covering the culture effectively spreads innovation in that system. For example, the country plays a role in regulating production and legal policies for the welfare of citizens in exchange for taxes. On the other hand, the business world realized production investment and employment opportunities. Consumers are the end-users of the products, and consumers decide on the adoption of products and the continuity of production. A study showed that the primary function of food packaging, according to respondents, is primarily a protective function (23.8%) and information function (23.8%). The analysis of the research results also showed that the essential characteristics of the packaging for the consumer are: ease of use and durability, while the most critical information sought on the packaging is: shelf life, price, and composition of the product. Consumers are also interested in information about the caloric content, individual nutrients, and a food product's origin (Wyrwa and Barska, 2017).

People tend to be conditioned in their eating behavior according to their emotional patterns or even to make variable food choices according to their current mental state and mood. Emotional eating corresponds to a tendency to overeat in response to negative emotions such as anxiety or irritability. Vandermoere et al. (2011) examined the potential of nanotechnology on the acceptance and buying willingness of consumers. According to the multinomial logistic regression analyses, the knowledge about food risks and nanotechnology significantly influences people's views about nanotechnology food packaging. On the other hand, Daoud and Trigui (2019) studied the factors influencing consumer's perception and how they evaluate the information provided by smart packaging. According to them, the success of an innovation depends on the type of food products.

Aday and Yener (2015) identified the purchase behavior of consumers with regard to innovative food packaging techniques and sociodemographic properties of consumers in Turkey (the crossroads of Europe and Asia). Their results showed that some consumers had problems concerning the trustworthy of the brand used the innovative packaging technique. On the other hand, the majority of consumers linked the innovative packaging including nanopackaging with higher prevention against microbial spoilage. Respondents revealed the importance of the education through commercials that could be the most effective way in order to increase the overall acceptability for innovative packaging. In Taiwan, although many publics have limited knowledge about nanothechnology, the Taiwanese consumers are optimistic on the technology applied in food products as long as the benefits of nanotechnology are exposed by media to improve the public perception (Chen et al., 2013). In the United States, the similar positive responses are also found (Cushen et al., 2012). In contrast in Europe, a certain reluctance to buy foods produced using nanotechnologies due mainly to the following factors: a comparatively higher perception of risks associated with the new technologies than the expected benefits; a low level of trust; a certain degree of food technophobia (Sodano et al., 2016).

Katare et al. (2016) evaluated the impact of information on consumers' willingness to pay for nano-packaged food products with varying shelf-lives using eye-tracking technology and experimental auctions. They revealed that the general and specific information about nanotechnology had a positive effect on consumers' willingness to pay for all nano-packaged products. Results showed that package information was crucial and could change consumers' attitude and the willingness to buy nano-packaged food products. The perception of consumers toward nanotechnology in food packaging is highly linked with the lower level of knowledge of the consumers. Results further suggested that social trust in the food industry is an crutial factor directly influencing the buying behavior. The social trust to nanofood products can be improved by developing regulation of nanothechnology in food products. Currently, The United States, Japan, Germany and China have been leading nanotechnology applying in food with regulation proving better open markets for the new technology (Bumbudsanpharoke and Ko, 2015). Safety regulations and risk assessment should be followed, since those issue are rising in consumer knowledge.

Changes in lifestyles with less time for consumers to prepare food gave a significant challenge for the food sector to find opportunities to produce food that can be prepared quickly, maintaining the nutritional value with new packaging techniques. Recent trends in the search for innovative packaging solutions are focused on nanopackaging, active packaging, smart packaging, and bioactive packaging which include intentional interaction with food and the environment (Guiné, 2021; Popovic et al., 2019). Packaging technology is part of the food product policy, which is of great importance for commercial enterprises regarding consumer gain. For some consumers, the packaging is seen as a convenient tool, while for others, it is used as a marketing ploy to sell the product (Table 4).

Table 4
Packaging as factor influencing consumers' decision to purchase food products.

Study	Methodology of the study	Main results	References
Examining attitudes and behaviors of consumers toward packaging of food products	Empirical study	The most important features of packaging for consumers are the comfort of use and durability	(Wyrwa and Barska, 2017)
Studying relation between packaging and perception of customer	Rule-based design system was used; the experiment package is shown to 300 respondents with mixed age and background.	the proposed rule-based system shows good consistency between satisfaction factors of a potential customer and food packages	(Auttarapong, 2012)
Studying the acceptability of smart food packaging technologies and determined their associations with sociodemographic, attitudinal, and behavioral characteristics of consumers in China	Quantitative survey using an intercept method in Beijing with one for intelligent food packaging and the other for active food packaging.	Smart packaging was accepted by 56% of participants Marital status and employment status were associated with the acceptance of active packaging, while consumer interactions with current food packaging were associated with the acceptance of intelligent packaging.	(Li et al., 2020)
Studying public acceptability of nanotechnology applied in food products and food packaging	Questionnaire asking the question 153 participated people related to social trust on the responsibility in using nanotechnology in food products and food packaging.	The consumer acceptance can be improved with a knowledge of consumers and with social trust of companies producing nano-packaged foods.	(Siegrist et al., 2007)
Studying public attitudes of Taiwan people on benefits and risk perceptions of nanotechnology applications	Questionnaire survey to 900 participants from 22 cities in Taiwan, analyzed empirically on attitude of public toward nanotechnology knowledge, social trust, public's benefits and risks perceptions of nanotechnology.	The more benefits a person observes, the more favourable the public's opinion toward nanotechnology applications. The greater the perceived risk, the greater the negative attitude toward nanotechnology applications.	(Chen et al., 2013)
Studying the consumer acceptance of nanotechnology application in food products in Italty	Questionnaire administrating 300 Italian people asking information related to consumer willingness to purchase six different nano-based food products.	The Italian consumers are certainly reluctant to purchase the food products with nanotechnologies due high risks, causing a low level of trust and technophobia	

The strength of the packaging, the shape, the size, the weight, the material, the colors, and the graphic arrangements made by the graphic designer is chosen to impress the user (Popovic et al., 2019). The care shown on the packaging is also a mirror of the general understanding of the company's quality, technique, and experience. Packaging that is functional and cost-effective is an important element of marketing. On the contrary, a product that cannot be protected or stored because its packaging is insufficient, making it difficult for the consumer to use it, and does not comply with health rules, cannot be competitive enough. In addition, well-designed packaging creates an effect to increases sales (Majid et al., 2018) due to the increased willingness to pay for a product packaged well. For example, Vandermoere et al. (2011) studied consumer acceptance for nano-packaged food products with information from various sources. The results indicated that the information from different sources affects differently the consumer acceptance for and attitude toward nano-packaged food products. Interestingly, they revealed that for plain-labeled food products, reliance on government regulation was the only determinant influencing participants' willingness to pay. On the other hand, when detailed information were provided, concern about the environment/health became the only factor that significantly influenced participant willingness to pay for nano-packaged food products. On the other hand, characteristics inherent in the food that influence the consumer's attitude when buying a product are color and aroma and external characteristics such as information and packaging, individual differences: biological (hunger, appetite, and taste), physical (access, skills for cooking and time), psychological (mood and stress), cognitive (attitudes or preferences, beliefs, and knowledge), and social (family and peers) characteristics related to culture, economic variables such as price and income, as well as politics (Chen and Antonelli, 2020). Erdem (2014) examined how consumers' preferences for chickens under different levels of food-borne health risk, animal welfare and price attributes vary according to the risk reduction method. The results show evidence of heterogeneity in preferences and willingness- to-pay values of the both consumer groups. They demonstrated that consumers in general showed no strong preferences towards or resistance to nanotechnology.

Factors influencing the consumer preference consuming products packaged with nano-based packaging needs to be considered in the future. The effects of nanopackaging are still on debate among researchers the extent of migration and whether it is negligible and safe (Bumbudsanpharoke and Ko, 2015). The regulations and conclusive legislations need to elaborated to clarify the health risk of nanopackaging for human health.

Psychological aspect of food packaging design

The first contribution of this study lies in the conceptual model proposed to explain how consumers' intention to buy a food product is positively influenced by the perceived responsible nature of the packaging in which the product is presented. D'Astous & Labrecque (2021) presented a conceptual model that offers a comprehensive explanation of the psychological mechanisms that consumers use when considering buying a food product, namely through the impact of the putative package on the formation of perceptions of both the naturalness and the health of the product. According to their results, innovative packaging (recyclable, reusable, and compostable) has a positive and statistically significant impact on consumers' intention to buy it, and it is through the consistent mediation of the perceived naturalness and health of the product that this relationship develops. Lack of knowledge among consumers about innovative and emerging food technologies such as nanopackaging can be a significant obstacle to their adoption. Consumers are open to packaging and convenience-oriented innovations, provided they do not change the main inherent characteristics of the product. In addition, changes in sensory quality, such as modified flavors, are not welcome in traditional foods. Consumers emphasize the authenticity and origin of conventional foods and improve their shelf life but reject innovations such as nanopackaging that may affect the product's sensory properties Kombanda et al. (2022) examined the socio-psychological factors associated with the consumption of low-energy foods by young Australians between 18 and 30, taking into account the food-related lifestyle as a potential framework. Five main factors were identified: psychological

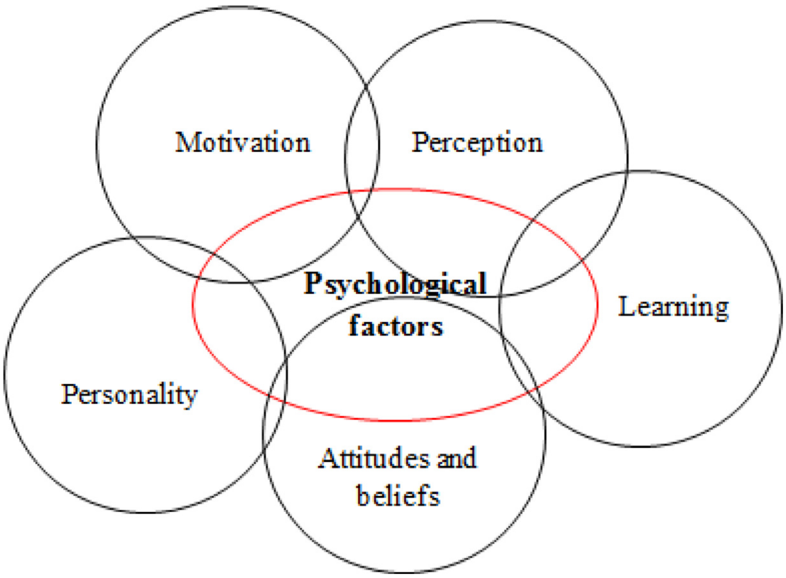

Fig. 6. Psychological factors influencing food intake.

factors, intrinsic qualities of food, social elements, affordability and accessibility, and health-related beliefs.

Psychological factors (motivation, perception, learning, attitudes and beliefs, and personality) were identified by participants as influencing factors on their food intake (Fig. 6). Motivation is the driving force and element that influences the individual to act or choose one course of action over another. Therefore, each motive aims to provide satisfaction and reassurance, and once a motivated behavior does not reach its goal, this motive becomes even more intense. From the point of view of marketing understanding, the important thing is to correctly define these motives and reveal the real reasons that influence the individual's behavior. Recognizing various stimuli in the environment with the sense organs is called perception. Learning affects human perception, and it can be defined as a change in behavior as a result of experience. Attitudes and beliefs directly influence consumer perceptions and behavior. Attitudes can be defined as a person's continuing behavioral tendencies, feelings, or evaluations of particular objects or ideas. For this reason, attitudes include both intellectual processes and emotions, and their intensity varies. Attitudes can create distortions in the perception of the message and affect the degree of recollection of the message. On the other hand, beliefs can be given as information that has been proven to be confirmed as a result of information obtained through external research or personal experience. Personality, biological and psychological, is the sum of characteristics. There is a close connection between the personality of an individual and the goods and brands that one buys. In other words, different personality traits influence buying behavior.

Psychological factors can influence the final choice of food directly or by influencing consumer attitudes. For example, Ahmed et al. (2014) determined the role of packaging on consumers' buying behavior and concluded that the packaging elements like its color, packaging material, design of wrapper, and innovation are more important factors when consumers make any buying decision. On the other hand, Boca (2021) demonstrated a positive relationship between consumer preference, consumer attitude, and consumer behavior variables. Kovács et al. (2022) investigated the importance of product attributes related to local products, and the motivational factors that determine purchase intentions. Authors identified the drivers of food choice sustainability expectations, the emphasis on environmental and social responsibility, and the changing consumer needs, of which the desire for healthy and quality products, curiosity, uniqueness, and experience are the most prominent drivers. Today's customers are becoming more aware and open to culinary discoveries and exotic delights. Roosen et al. (2015) analyzed the role of trust in the evaluation of nanotechnology. According to authors, the willingness to pay for new food characteristics increases with trust also when new information about the technology is revealed. Gómez-Llorente et al. (2022) evaluated Spanish consumers' opinions on using nanotechnology in food processing and packaging. According to their results, the respondents had a medium neophobia level, being consumers with more knowledge about new technologies the least neophobic and those who gave products higher scores.

Neophobia and health risk are the most rising issues for consumers not to consume products with nanopackaging. Media and publishers play important role on communicating with consumers and provoking other stakeholders, e.g., government with regard to the national regulation of nanomaterials in food packaging and Industry with regards to the implementation of the nanotechnoly in food packaging (Bumbudsanpharoke and Ko, 2015; Sodano et al., 2016). Policymakers should engage in communication with the goal of enhancing public acceptability, communicating benefits, and encouraging more trust in industry and research. The desire for a far more open and responsible introduction of new technology to the market may be at the heart of consumers' hesitancy (Sodano et al., 2016). As a result, policymakers should avoid communication initiatives focused at promoting public acceptance and instead intervene to address all the hazards connected with new technologies.

Conclusion

The great craze for safer and higher quality food has led to the introduction of new and more intelligent packaging strategies. Nanopackaging solutions for food safety and quality have gained the significant interest of consumers for a variety of food products. They help to minimize food waste and loss by ensuring strong antimicrobial activity, imparting antioxidant power, and enhancing sensory acceptance. In addition to the health effects, sensory quality and ease of use are still very important to consumers. The inherent characteristics of food that affect most consumers' purchasing behavior are color and smell, as well as external characteristics such as labels on the packaging, and individual cultural differences. Nowadays nanopackaging is a promising method of food wrapping, but the lack of consumer knowledge of innovative and emerging food technologies could be a significant barrier to the adoption of this technology. In this context, more efforts should be made to increase public knowledge, awareness, and confidence to facilitate the shift toward more sustainable packaging solutions. Furthermore, global consumer demand is driving research and development of new materials to find alternatives to fossil packaging materials. Both consumers and the food industry are looking to replace unsustainable and environmentally damaging packaging materials (such as plastic) with recyclable, biodegradable, or edible materials made from renewable and sustainable sources. However, some issues related to the safety of nanotechnology products are still of major concern. The different materials used in these new packaging designs raise questions about their adverse health effects on consumers. Therefore, research avenues to assess the health and environmental impacts of these nanoparticles are open and unlimited. To comprehend social factors on consumers toward new food trends is essential to promote packaging that is suitable to social norms and culture. This indicates that social and psychological motivation factors strongly affect consumers toward new trends in food consumption.

Ethical statement

This study involved no tests on humans or on animals.

Funding

This work was funded in part by the USDA/NIFA through the Agricultural Research Program at North Carolina Agricultural and Technical State University (Evans-Allen Program, project number NC.X-291–5–15–170–1) and by an 1890 Capacity Building Program Grant (No. 2020–38,821–31,113/project accession No. 021,765). We would like to acknowledge the support of the Agricultural Research Station at North Carolina Agricultural and Technical State University (Greensboro, NC, United States). This research was funded, in part, by grants (Project Nos. NC.X337–5–21–170–1 and NC.X341–5–21–170–1) from the National Institute of Food and Agriculture (NIFA).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Shahida Anusha Siddiqui: Conceptualization, Methodology, Validation, Supervision, Writing – original draft, Writing – review & editing, Visualization. **Oscar Zannou:** Writing – original draft, Writing – review & editing. **Nur Alim Bahmid:** Conceptualization, Methodology, Writing – original draft. **Hafize Fidan:** Methodology, Writing – original draft. **Abdel-Fadel Alamou:** Writing – original draft, Writing – review & editing. **Andrey Ashotovich Nagdalian:** Methodology, Data curation. **Abdo Hassoun:** Methodology, Validation, Data curation. **Ito Fernando:** Validation, Writing – original draft, Writing – review & editing. **Salam A. Ibrahim:** Funding acquisition, Validation. **Muhammad Arsyad:** Supervision.

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