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Consumer Studies Focus on Prebiotics, Probiotics, and Synbiotics in Food Packaging: a Review

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Abstract

Purpose of Review Dietary consumption of prebiotics, probiotics, and synbiotics has been suggested to improve human health conditions. Functional food products containing live probiotics are flourishing, and their demand seems to be increasing since consumers are more aware of the health benefits of such products. However, specific food packaging is needed to maintain the viability and stability of these products, hence, necessitating advanced technology and processing. This study intends to give academics and industry an overview of food packaging evaluations that concentrate on prebiotics, probiotics, and synbiotics for consumers to gain a wide and clear image.

Recent Findings This review provides recent findings from the consumer point of view on the prebiotics, probiotics, or synbiotics incorporated in food packaging based on consumer behavior models. Additionally, various obstacles in the preparation of packing film or coating added with biotics are identified and described. The health benefits of prebiotics-, probiotics-, or synbiotics-containing edible film or coating are also discussed. Future works needed to excel in the preparation and potential of packaging film or coatings with biotics are provided.

Summary The development of prebiotics, probiotics, and synbiotics in food packaging is discussed in this study from the consumer's point of view. With this review, it is hoped to be able to provide precise recommendations for the future development of food packaging that will promote the growth of the food business.

Keywords Functional food · Consumer behavior models · Health benefits · Packaging film · Coating

Introduction

People are becoming much more conscious of the medicinal benefits of various types of foods like probiotics, prebiotics, and synbiotics [1]. Consumer awareness about the importance of diet in maintaining good health has led to an increased market for synbiotic food classes. Due to the widespread usage of antibiotics and bacterial resistance, as well as the interest in ecological approaches in the management of diseases, probiotics, prebiotics, and synbiotics are exciting research areas [2]. Probiotics are described as living bacteria that, when taken in appropriate quantities, provide positive health effects on the host [3]. Their functions encompass counteracting local immunologic dysfunction, stabilizing the intestinal barrier function, and preventing a succession of pathogenic microorganisms. However, the production of more advanced synbiotics at affordable prices for the food industry requires extensive innovation in manufacturing technology. In short, the growing public awareness of the significance of probiotics, prebiotics, and synbiotics in food and the body, as well as the connection between diet and health, is encouraging the development of functional food products and packaging and the increasing popularity of pre-, pro-, or synbiotics among global consumers.

Many researchers recognize that probiotics can be delivered through foods. Therefore, probiotics can have beneficial effects when added to supplements and foods [4–7]. Since more and more bacteria are being discovered with health benefits, a growing interest is being expressed in developing new foods. The survival of living bacteria relies on their environment since they often require strict nutrition requirements. For instance, prebiotics are non-digestible

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carbohydrates selectively fermented to stimulate bacteria in the intestines [8]. Because of an absence of appropriate microflora, the upper part of the gastrointestinal tract provides resistance to their digestibility. However, once they reach the large intestine, the microbes present there degrade them and extract the nutrients needed for their survival [9]. A small portion of carbohydrates also escapes, which serves as a nutrient for nearby bacteria. Thus, the vital gut microbiota contributes to the health of gastrointestinal cells by stimulating the blood flow within these cells [10]. Recognizing the importance of probiotics to the human body, an increasing number of consumers are seeking functional foods for their substantial health benefits, as evidenced by their current purchasing patterns [11, 12].

Since their inception, synbiotics, probiotics, and prebiotics have received a lot of attention. This is most likely due to the fact that when customers consume synbiotic foods, their bodily health can be maintained and even improved [13]. Moreover, health-based fermented foods contain highly effective strains of probiotic bacteria, and prebiotic compounds have been synthesized [14]. Scientists are researching affordable fermenting techniques for enhancing the synbiotic health benefits of novel and creative fermented foods. Microencapsulation is promising for producing innovative functional foods. Current findings emphasize the challenges of microencapsulation of probiotic cells and the variety of food systems used to manage carrier foods [15]. The microbiome of the human intestinal tract plays a vital role in improving nutrient absorption and promoting human health. During bio-fermentation, gut microorganisms transform a variety of dietary nutrients into compounds such as vitamins, organic acids, and short-chain fatty acids [16]. Accordingly, an optimal equilibrium between the intestinal microflora and the occupant is needed. This equilibrium may be disturbed depending on factors such as eating habits, medicines, stress, and other lifestyle elements, contributing to the spread of infectious species [14]. Several gut diseases may result, including colon cancer and chronic bowel disease. Consequently, preserving or even improving standard gastrointestinal microbiology may be achieved by understanding gut microbiota and its dynamics [17]. To modulate the target gastrointestinal microflora balance, prebiotics, probiotics, and synbiotics have been developed [18].

Given the importance of probiotics and prebiotics to the health of consumers, control and prevention measures are necessary to ensure that the probiotic and prebiotic content of food remains safe. This is due to the presence of potentially harmful factors during food processing, such as mechanical processing, heat, acid, and osmotic pressure [19]. In addition, the storage procedure involves the transfer of moisture and oxygen, which might result in an inappropriate distribution of probiotic cells, which are exposed to low pH and bile in the digestive system [19]. To address this problem, one of the newest ways (packaging) to keep the number of microorganisms at the recommended dose has been introduced; this method involves putting live cells in a low-humidity bed [20••]. In a novel strategy, probiotics may be included in edible film and coatings comprised of natural polymers and thin layers of plastic [21–25].

Consumers understand that health is the most important consideration in the food and packaging system, but they are also becoming more concerned about environmental factors [20••]. As a result, numerous environmentally friendly packaging technologies, such as biopolymer packaging, have arisen to prevent food from spoiling and increase its quality by shielding it from gases and moisture [20••]. Also, the combination of prebiotics and probiotics, which is often called “synbiotics,” is being used more and more in food packaging systems because it can carry bioactive compounds like vitamins, enzymes, and antioxidants and eventually release them into food products [26–28]. Furthermore, there are an increasing number of food packaging solutions, such as coatings that may be consumed with the food [29]. With more sophisticated food packaging technology and consumers becoming more conscious of food safety, this review provides a consumer viewpoint on prebiotics, probiotics, or synbiotics included in food items and food packaging based on consumer behavior models for food packaging development.

Bearing in mind the aims, several factors connected to the development of more advanced food packaging technologies and consumers who are increasingly cognizant of food safety; this review intends to present a customer point of view about prebiotics, probiotics, or synbiotics incorporated in food and food packaging. This study will also considerably assist stakeholders and policymakers in linked sectors in gaining direction and a clear image of the future of food packaging that customers really desire. Furthermore, this study will assist researchers in determining current advancements, trends, and gaps in the development of food packaging in order to generate an idea for future research that may be created.

Prebiotics, Probiotics, and Synbiotics in the Food Industry

Prebiotic

Gibson and Roberfroid [30] defined a prebiotic as a non-digestible food substance that favorably influences the host by enhancing the growth and function of one or a specific number of bacteria in the colon. In addition, prebiotics are classified as unviable food substances that provide a health impact on the host due to influencing the microbiome [31]. It has been scientifically proven that prebiotics are effective dietary supplements for regulating the proliferation and function of particular bacteria in the colon, having beneficial health effects. Prebiotics are believed to play a selective role in the microbial community contributing to improved health of the host. Consequently, a compound is deemed prebiotic if it exhibits the following characteristics: indigestibility and fermentation resistance due to microbiota in the large intestine and a particular effect of the microbiome. So long as prebiotics and other low-digestible carbohydrates are not metabolized, they possess an osmotic effect in the gastrointestinal tract when the endogenous bacteria ferment them. Two factors play a role in the prebiotic, or rather bifidogenic, effects: the kind of prebiotic and the amount of bifidobacterial present in the host [32]. The common prebiotic compounds are classified in Fig. 1. Prebiotic compounds are derived from plants, vegetables, fruits, milk, etc., and have properties similar to dietary fibers [33].

Probiotics

Probiotics are considered to be living microorganisms (such as yeast and lactic acid bacterium) that have a beneficial influence on the host's health [34]. It is important to note that strain-specific health benefits do not apply to species or genera. In addition to being beneficial for human nutrition, probiotics produce bactericidal compounds like bacteriocins, adhere to human intestinal cells, and populate the colon. By metabolizing carbs and sugars, microorganisms support the digestive process by enhancing immunity, ensuring optimal gastrointestinal acidity, and efficiently interacting with pathogens [35]. It has been demonstrated that several strains of probiotics have modulated the microflora in the intestine to reduce the duration and frequency of diarrhea caused by rotaviruses [36]. Ingestion of probiotic foods can have non-specific effects, such as decreasing gut leakage, stimulating mucin production, suppressing pathogens, promoting natural killer cells, and activating macrophages. Adaptive immune system production of antibodies can be increased by producing cytokines and other regulatory elements. Probiotics are typically available as foods or medications. *Pediococcus*, *Leuconostoc*, and *Lactobacillus* species have played an essential role in food preservation during human evolution, and consumption of foods containing living or dead microorganisms and their byproducts has been ongoing for a long time [37]. Commonly used probiotics include *Bifidobacteria*, *Lactobacilli*, and certain harmless bacteria specifically originating from humans, which benefit the host and may avoid or treat various diseases once consumed in sufficient quantities [38]. Probiotics need to stay viable while being stored, processed, and moved through the human body. The efficacy of a probiotic product should be confirmed through rigorous testing, including strain testing, genotype and phenotype characterizations, functional analyses, and risk assessments. It is also necessary to consider the procedures for evaluating probiotics in food. *Lactobacilli*, *Enterococci*, and bifidobacterial are commonly found in probiotic foods

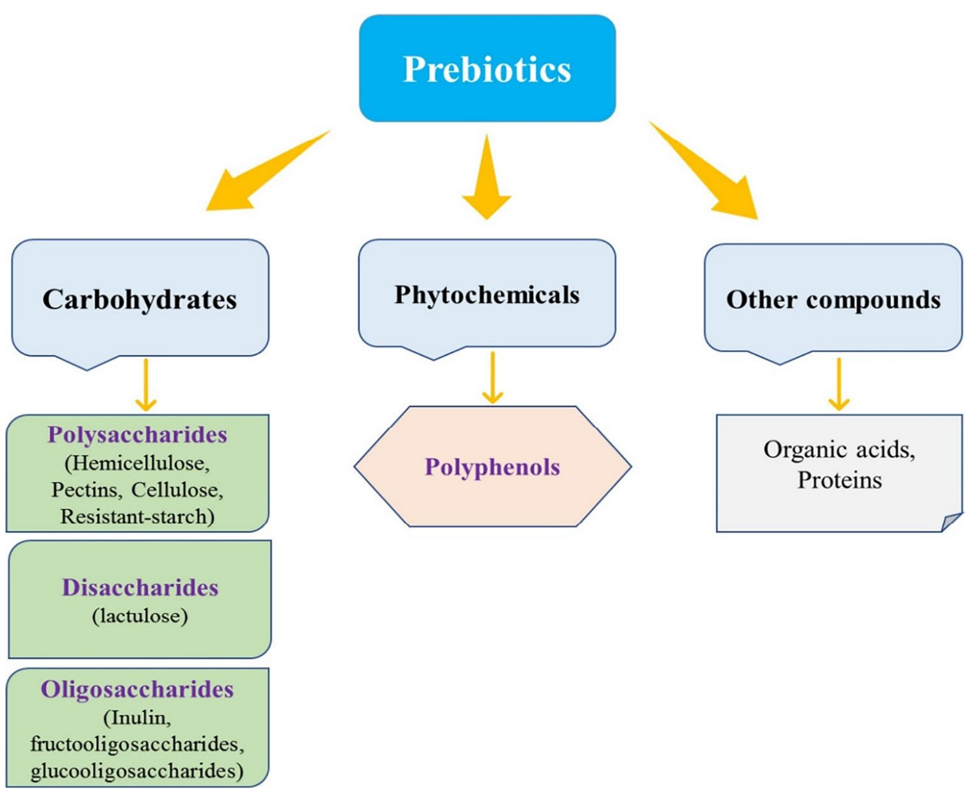

Fig. 1 Common classification of prebiotic compounds includes carbohydrates, phytochemicals, and others

[39]. Bacteria used in probiotics are primarily lactic acid bacterium strains, *Enterococcus*, *Bifidobacteria*, and *Bacillus*. As a human probiotic, *Saccharomyces boulardii* is also employed, though in the form of a powder or capsule [3]. Several microbial species appear secure, but specific species may induce some issues. As hospital environments have evolved, enterococci have become ubiquitous agents responsible for various infections [40].

Generally, probiotics are living organisms, primarily bacteria and yeasts, that bind to the host and gut microbiota when consumed in sufficient quantities, providing health benefits beyond nutritional ones. Traditionally, the security of unknown species has been determined mainly by their appearance in food or as normal bacteria in the human intestines. Probiotic organisms can be accepted as nutritional additives, approved medications, or mixed into diets, depending on various conditions [41]. Moreover, foods and food components that consist of, or incorporate, GM organisms, bacteria, or fungi are categorized as novel foods [42]. Nutrient considerations play a crucial role in toxicological tests conducted on animals. The maximum level of dietary incorporation achievable without causing nutritional imbalance should be the highest possible level to allow careful interpretation of negative reactions seen in animal studies while distinguishing toxic effects from those caused by a nutritional imbalance in the experimental diet and study design [43]. Ideally, the lowest dose level will be comparable to its expected human diet role. In addition, a case-by-case evaluation of the toxicological criteria for novel foods is required. In a worst-case scenario, it is necessary to consider the assessment of the toxic potential of chemical compounds determined experimentally, toxicological studies, allergy testing, and prolonged feeding experiments [43].

Synbiotic

Synbiotics are formed when probiotics and prebiotics are coupled [44]. Synergistic effects between probiotics and prebiotics are significant due to the advancement of preserving and introducing living microorganism supplements in the gastrointestinal tract [41]. Synbiotics offer the advantage that probiotics are more readily available in the gastrointestinal tract. Many studies on synbiotics have been published with data from both in vitro and in vivo experiments [45, 46].

A single strain of probiotics may not be able to profoundly affect the complex gastrointestinal microbiome, as well as the complicated interactions between the host and the bacteria. Prebiotic has been found to significantly impact gut bacteria in a way similar to xylooligosaccharides [47]. Consumption of those products could change the structure and function of gastrointestinal bacteria. Eczema in infants has been controlled by combining oligosaccharides with probiotics [48]. An essential component of the effectiveness of synbiotics is their safety.

Consumer Behavior Models to Predict Prebiotic, Probiotic, and Synbiotics in the Food Packaging Industry

Approximately sixteen centuries ago, edible food packaging was originally created and introduced in Japan using soy milk-based edible film to preserve fruits and achieve a lustrous appearance [49, 50]. However, owing to the limited selection of materials available at the time to preserve fruits and vegetables, there was little interest in this type of packaging [33].

When compared to edible packaging, refrigeration, controlled/modified atmospheres, heat or radiation sterilization, and smoking were techniques of major concern and were frequently utilized to extend the shelf life of food products and prevent contamination from microbes [33]. Furthermore, many modern technologies have been brought to the market in this modern era, such as food conservation techniques, which may provide limitless options to preserve all types of food so that consumers can consume all types of food in any season [33]. However, the quick advancement of technology has resulted in an evolution in edible packaging, making it adaptable to a broad range of food products and also having a distinct style of operating, suited to innovation from conventional food preservation techniques [51].

Moreover, conventional synthetic packaging has been shown to have a negative impact on the environment [52]. Due to the many losses produced by traditional synthetics such as films, a sustainable packaging solution that can extend the shelf life of food products and protect them from microbial contamination is required [51]. In addition, edible packaging has gained favor in the scientific community as a replacement for traditional packaging that is environmentally friendly, and this has drawn the attention of authorities and environmentally conscious consumers [51, 52]. This is also confirmed by a number of prior research indicating that consumers are more accepting of prebiotics, probiotics, and synbiotics in food packaging [53–55].

Probiotic products are in great demand among consumers, particularly the younger population [53, 56]. Probiotic nutraceutical products are a type of functional food that has been shown to improve gastrointestinal function as well as provide other advantages such as increased immunity. According to Mordor Intelligence (2018) [57], the worldwide probiotic products market was valued at US$46.54 billion in 2017 and is predicted to increase at a compound annual growth rate (CAGR) of 7.5% from 2019 to 2023. Following the Covid-19 pandemic, demand for functional foods and immune-boosting supplements has increased dramatically, resulting in a surge in demand for products that boost immunity [58–60]. This is because during and after COVID-19 people are more aware of the importance of food that can support and boost their body's immune so that they are less prone to illness and can protect them against all assaults of disease and may even speed up recovery if they are sick [60]. Moreover, a growing robust consumer demand for natural products and increasing concerns on preventive health care have significantly helped in the expansion of the pro- and prebiotic market.

In addition, as the timeframe between food production and consumption from the farm to the fork increases, so does the need for food packaging [20]. Food packaging is critical as it can protect against spoilage, dehydration, loss of quality, appearance, and nutritional content while the food is being handled, stored, or transported [61]. However, the most commonly used food packaging materials are polymers, which have caused environmental problems due to their inability to biodegrade [62]. Therefore, the use of edible and biodegradable packaging systems (films/coatings) as sustainable food packaging is a technology that is flourishing globally and is preferred by a large number of consumers [63]. In addition to being renewable, recyclable, and biodegradable, the materials used to produce edible packaging need minimum or no disposal [64, 65]. In addition, edible and recyclable packaging materials often include prebiotics, probiotics, or synbiotics, which has led to an increase in demand for food packaging products containing these components. This may also affect consumer purchase behavior to prefer food and packaging products containing prebiotics, probiotics, and synbiotics since they are safer and more environmentally friendly.

When we witness the extremely positive effect of edible food packaging on the environment, whether this also correlates with consumer perceptions and desire to eat edible food packaging is questionable [54]. Moreover, Sevi et al. [55] found that Indonesians are interested in using edible packaging for chili powder products and they are also eager to eat edible packaging together with their food products. Aside from edible food packaging for agricultural products such as fruit and vegetables, many consumers are starting to accept edible packaging for other food products like edible water bottles, edible coffee cups, and edible cupcake cases [66]. However, since edible food packaging is still not widely known by the wider populace, an effective marketing approach, such as a short explanation of the advantages of consuming edible food packaging, is required to attract consumers' purchasing intents [67]. Since the success of a product in the market is significantly determined by the number of consumer acceptance of a product; thus, to promote the success of edible food packaging incorporating pro-, pre-, and synbiotics, more in-depth research is required on consumer behavior. It is very much important for a business to have access to data regarding purchasing behavior of consumers so as to develop successful marketing models [68]. The purchasing behavior of the consumer can be affected by (i) cultural, (ii) social, (iii) personal, and (iv) psychological characteristics [69, 70]. In general, culture is an integral aspect of any civilization and is highly influential on individuals' desires and behavior [71]. There can be many other subcultures such as nationality, religion, geographic areas, and racial groups that can exist within a culture. Moreover, consumer behavior can also be influenced by social class, which is the hierarchical partitioning of society into several sections based on their social status. Social class influences consumers' lifestyles, purchasing habits, hobbies, and interests. Social factors such as family, and reference groups (those groups having a direct or indirect impact on an individual's views and conduct) can also influence the buying behavior of a consumer. The personal factors that influence buying behavior are age, occupation, lifestyle, and personality. The four major psychological elements that influence customer purchasing decisions are motivation, perception, learning, and beliefs and attitudes [69]. Motivation is one of the major psychological factors that affect buying behavior. Maslow's Theory of Motivation explains why humans are motivated by different needs at different times. Maslow created a hierarchy of human needs based on their relevance. Physiological needs, safety needs, social needs, esteem requirements, and self-actualization needs are the five types of needs. A person attempts to meet their most basic needs first. A need changes to one's motive when it is more pressing for a person to seek satisfaction. And another important factor in deciding purchase behavior is the individual's perception, which corresponds to what the individual thinks about a particular product or service. Consumers with similar needs may not purchase the same product due to their differences in perception. Further, there is a high level of acceptance by consumers in general of the numerous aspects of the consumer behavior model that might impact the acceptability and purchase of food products and packaging derived from prebiotics, probiotics, and synbiotics [72]. This may be because consumers are already aware of the health advantages of purchasing and consuming prebiotics-, probiotics-, and synbiotics-containing food products and food packaging [73]. Therefore, it can be concluded that products including prebiotics, probiotics, and synbiotics have excellent development potential, particularly in the food business [72].

Consumer Buying Behavior Models

Currently, there are several different models used to predict consumer buying behavior. A simple conceptual model consists of the following steps as shown in Fig. 2: (i) the consumer identifies an unsatisfied need; (ii) after the need is recognized, the consumer searches for information from different sources such as public, personal, or commercial;

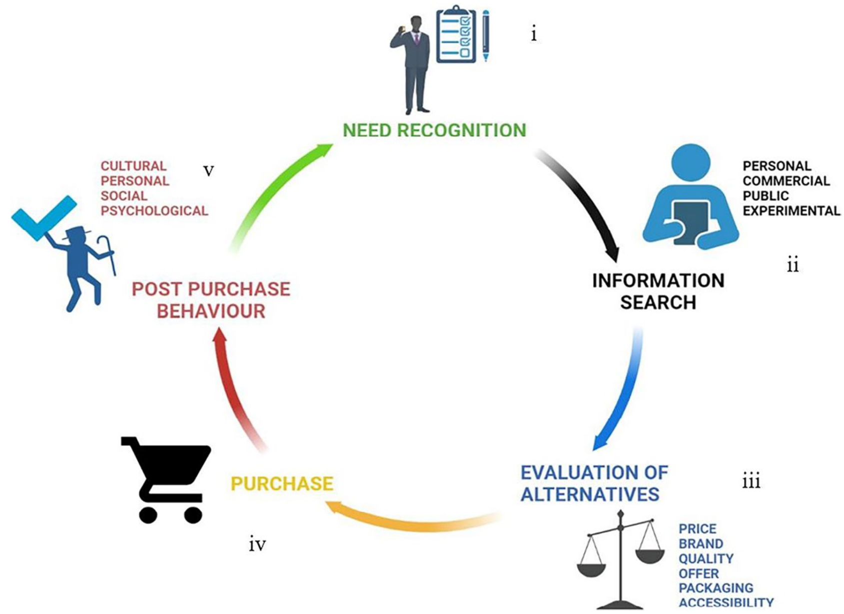

Fig. 2 Consumer buying behavior (a conceptual model)

(iii) the consumer receives a variety of alternative choices and evaluates it with respect to various criteria such as price, quality, brand, and accessibility, and selects the best one; (iv) after selecting the best choice, consumers go to the following stage, which is to buy the goods; and (v) the last stage is the post-purchase decision, where the consumer would continue to purchase the product according to the personal satisfaction with the product.

The consumer buying models, in general, help us to visualize and understand various consumer decision processes and provide a frame of reference for changing variables and market circumstances. One of the successful models that can be used to study the consumer buying behavior of probiotics, prebiotics, and synbiotics is the Health Belief Model (HBM) [74•]. The goal of developing the Health Belief Model was to investigate individual differences in decision-making for accessing health services in the USA which are connected to the desire to prevent and alleviate sickness [75]. This model can be used to predict the individuals who participate in health behavior because they feel that doing so would improve or minimize the severity of their health condition. The HBM focused on two components of individuals' representations of health and health behavior: behavioral assessment and threat perception [76]. Threat perception can be defined by two main beliefs: perceived vulnerability to disease or health issues and expected severity of illness repercussions, whereas behavioral assessment includes two unique sets of beliefs: those about the benefits of prescribed health behavior, and about the costs of or obstacles to adopting the behavior. A recent study by Chong and Teh [77] on the buying behavior of probiotic and nutraceutical products among the Malaysian population showed that it is the belief in health-promoting effects of probiotic products and not the knowledge about the nutraceutical properties that significantly affect the consumers buying intentions. Another consumer behavior model that can be used to predict consumer acceptance of synbiotic products is the Theory of Planned Behavior (TPB). The Theory of Planned Behavior (TPB) forecasts an individual's intention to participate in a behavior at a specific time and location. A combination of HBM and TPB was used by Rezai et al. [78] to study the buying behavior of Malaysian customers on natural functional food. The study reported the perceived benefits (an assumption that a certain action will lower the risk or severity of the impact), followed by subjective norm (social pressure), and perceived susceptibility (the probability of being diagnosed with a sickness or condition) to be the most significant factors that affect the consumer intentions during purchase. Another important parameter that affects the consumers purchasing behavior is the willingness to pay (WTP). Pappalardo and Lusk [79] conducted a social experiment to study the consumers' WTP a higher utility price for functional food as compared to a conventional product using the Expected Utility Theory (EUT) and reported that the consumers' WTP depended not only on the functional component of food but also on other factors like price, naturalness, and safety. Also, Flora [80] said that the level of consumer knowledge affects how consumers accept food packaging with probiotics and how they choose to purchase it. Consumers who are knowledgeable about probiotics prefer to get and purchase food products and food with probiotic packaging [80].

Today, the increased awareness and health concerns of consumers have brought changes in their dietary habits, resulting in the formation of a market niche for probiotic foods and their packaging [80, 81]. Between 2014 and 2017, the number of probiotic supplements and vitamin product releases in New Zealand and Australia surged by 200% and probiotic, together with prebiotic food, was estimated to reach US$140 million by 2021 [82]. Given the prospective market for probiotics, it is critical to understand consumer behavior by taking into account both intrinsic and extrinsic factors such as psychological, emotional, social, cultural, and economic. Some of the widely used consumer behavior models that can be used to study synbiotics in food and packaging are discussed below.

- Economic model: The economic model of consumer behavior emphasizes the assumption that a customer's purchasing pattern is focused on maximizing benefits while reducing expenses. As a result, economic variables such as the customer's purchasing power and the price of competing items may be used to forecast consumer behavior. According to this method, a consumer must be informed of all possible consumption alternatives, capable of accurately assessing each option, and available to choose the best course of action.
- Psychoanalytic model: The psychoanalytical approach asserts that consumer behavior is influenced by impulses known as "drives" or "instinctive forces" which are operated by both the conscious and subconscious minds. Purchasing decisions and behavior are affected by three levels of consciousness discussed by Sigmund Freud (id, ego, and superego) [83].
- Sociological model: The sociological model focuses on the premise that a consumer's behavior is influenced by his or her social environment. Purchasing habits are influenced by consumers' social status. A consumer's purchasing behavior may also be impacted by the people with whom they interact and the culture in which they live.
- Nicosia model: The Nicosia model explains consumer buying behavior by establishing a connection between the firm and its potential customers. According to the approach, messages from the company first impact the consumer's propensity toward the product or service. This may result in the development of certain attitudes in consumers, leading the consumer to search for the product or evaluate the product's characteristics. If the preceding stage satisfies the consumer, it may result in a positive reaction, including a choice to purchase the product [84].
- Stimulus–Response model: Marketing and other stimuli (product, place, price, promotion, economic elements, technical, political, and cultural factors) penetrate the buyer's "black box," where they are transformed into observable buyer responses such as product selection, brand selection, dealer selection, and purchase time. Marketers must determine what is inside the buyer's "black box" and how stimuli are converted into reactions [85].

With the concept of consumer buying behavior toward food products and food packaging containing prebiotics, probiotics, and synbiotics, it is hoped that it will assist in the development and improvement of food products and food packaging in accordance with consumer preferences. In addition, the concept of buying behavior will aid decision-makers, the government, and related industries in developing food packaging products based on the flow of consumer purchasing behavior. Accordingly, it is anticipated that the strategic approach will be developed for the future growth of the food packaging industry.

Barriers to Widescale Applications of Prebiotics, Probiotics, and Synbiotics

Industries that utilize bioactive agents encounter challenges in generating steady components that keep the properties active through the manufacture and storage processes until consumption [86]. Several challenges may occur in mass production such as preserving the viability and functionality of bioactive agents, selection of packaging materials, and the types of carrier agents, as well as developing reliable technology for food packaging.

Viability and Functionality of Bioactive Agents

The primary role of the bioactive agents of prebiotics, probiotics, and synbiotics is to assist the existing intestinal flora in enhancing their habitat. By changing, replenishing, and adapting the intestinal flora, it is possible to increase their (prebiotics, probiotics, and synbiotics) resistance to the hostile gastrointestinal environment [87]. Furthermore, their viability (i.e., probiotics) may assist to manage intestinal microbial intervention via colonization by controlling microbe metabolism and promoting human health [87, 88]. Hence, prebiotics, probiotics, and synbiotics are all attractive research topics due to their considerable impact on human health.

Fructooligosaccharides, xylooligosaccharide, galactooligosaccharides, and inulin are common prebiotics [89–92]; meanwhile, *Lactobacillus*, *Bifidobacterium*, *Saccharomyces boulardii*, and *Bacillus coagulans* are common probiotics used in food products [93–95]. When both pre- and probiotics are used together (synbiotics), several advantages are improving their activity, survival, and ability against digestive bacterial infection [91, 96, 97]. Improving the viability of those components is a key point in reducing barriers to their widescale applications. Encapsulation, microencapsulation, and nanoencapsulation are widely used in enhancing the viability of these bioactive agents [98–100].

Encapsulation creates coating as protection for bioactive agents in unfavorable conditions, such as in the manufacturing process and storage as well as in the gastrointestinal tract [87]. The utilization of enzymes, cells, and other materials shrouded in capsules makes the bioactive agents stay active for delivery, which then released its content at the designated time and destination. Microencapsulation uses small particles surrounding the probiotic bacteria which protect the digestive system but can be broken when there is force [99]. Nanoencapsulation also prolongs the survival and viability of these bioactive agents, as well as a controlling agent for correct delivery [98, 101].

Recent studies on microparticles with prebiotics efficiently boost the viability of Lactobacillus acidophilus LA-5, that is, by conferring those bioactive agents to have a protective effect on the gastrointestinal tract [94]. For probiotics on livestock, microencapsulation by the spray drying method is strongly recommended since it could provide a high final bacterial concentration as well as it has a smaller particle size, thus making it easier for combining with livestock feed products [102].

The coating size and materials of capsules also influenced the capabilities in survival and viability of probiotic bacteria; the smaller the materials, the higher the protection ability against harsh environments, since they can fill in hydrogel structure pores of beads [101].

Packaging Materials

Packaging techniques and material constituents have been a concern in recent years. Dairy probiotics as well as other products mostly use plastic packages with oxygen permeability. Meanwhile, to preserve the viability of bioactive agents, retaining a low level of oxygen needs to be conducted. Several techniques such as adding oxygen scavengers, as well as vacuum packaging, may help to retain the bioactive agent viability [103].

However, sustainable and environment-friendly packaging is also an important aspect that has to be considered. Several biopolymers and biodegradable polymers have been introduced for food packaging which is in line with a sustainable environment [104]. Environment-friendly food packaging is now desirable since biodegradable polymers such as starch, casein or whey proteins, cellulose, polybutylene adipate terephthalate (PBAT), polybutylene succinate (PBS), and other biodegradable polymers are now commercially available [105–107].

In parallel, natural agents for micro/nanoencapsulation are also rapidly developing. Recent studies on hydroxypropyl methylcellulose containing carvacrol nanoemulsions improved the shelf life of food products [107] Similar results also occurred in those containing oregano essential oil nanoemulsions [108]. High antioxidant and antimicrobial properties are reported to play an important role in these regards. Polylactide films containing essential oils/nanoparticles have an antimicrobial effect against *L. monocytogenes* and *S. typhimurium* on contaminated cheese [109]. Alginate coating using basil oil nano-emulsified along with an extract of *Sapindus* is able to extend the shelf life of okra [110]. Starch-carboxy methylcellulose films that consist of rosemary essential oil have an antimicrobial effect against *S. aureus* in a new active film [111]. The extension of the shelf life of shrimp as well as the enhancement of its antimicrobial activity also occurred after using Cinnamon nanophytosomes embedded in electrospun nanofiber in its package [112]. Higher antimicrobial activities are accountable for these phenomena. Eventually, biodegradable packaging has great potential to meet the needs of renewable and food-grade ingredient materials which comprise convenience, safety, sustainability, and environmental friendliness.

In brief, several of the previously stated materials, such as biopolymers, biodegradables, carvacrol nanoemulsions, and essential oils/nanoparticles, are thriving materials that are extensively employed in the food packaging industry. The popularity of these materials is attributable to the fact that they have been evaluated in food packaging research, and many consumers are requesting food packaging that is both environmentally friendly and capable of keeping food in excellent condition for consumption and is also more durable for storage. Hence, the use of these materials in the production of food packaging is strongly advised in order to both preserve the quality of food and entice consumers to purchase it.

Innovations in Food Packaging

Traditional food packaging is challenged due to rising customer demands and increasing product complexity. For centuries, food packaging has evolved into a critical technology for ensuring food safety, avoiding unwanted responses, meeting customer expectations, and extending food shelf life (Fig. 3). Active food packaging with integrated oxygen barrier materials or films with selective permeability qualities has been applied for probiotic foods [113]. The major goal of active packaging, which is an alternative to traditional packaging, is to promote and maintain good quality while also extending the freshness of food products. To achieve this, various components capable of releasing/absorbing substances from/into packaged food can be integrated into

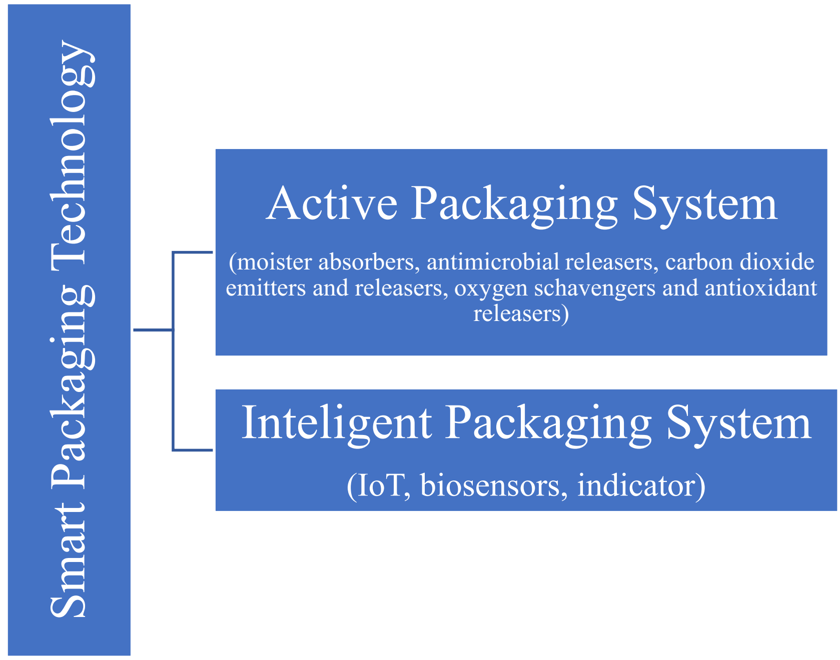

Fig. 3 Active and intelligent packaging system as part of smart packaging technology

the system to prevent spoilage [28]. Intelligent packaging methods are among the latest developments that have the potential to reduce food waste [114]. Intelligent packaging is primarily used to track and monitor the conditions of packaged foods, as well as to collect and send data on the product's state during storage and transit procedures [28]. With the incorporation of new electronics, wireless connectivity, and cloud data solutions, packaging systems have become smarter [28], and will contribute to the technology-mediated risk communication era [115].

Changes in consumer preferences, as well as the necessity for safe and high-quality meals, drive innovation in food packaging technologies. A smart packaging system is a combination between active packaging and intelligent packaging that work synergistically and are good instances of this food packaging evolution (Fig. 1). Smart packaging offers a whole package solution that, on the one hand, monitors and reacts to changes in the environment (intelligent) and/or in the product (active). Chemical sensors or biosensors are used in smart packaging to monitor food quality and safety from manufacturers to customers [116]. Nanotechnology is being recognized as a promising new technology for smart packaging systems [117]. Nano-enabled methods, such as nanomaterials and nanofabrications, have mostly been utilized to alter the shape and surfaces of platforms at the nanoscale to improve the functionality of food packaging systems. Smart packaging is an important part of the growing food industry 4.0, which includes adaptable production and intelligent tracking systems [118]. In general, smart packaging technology has a wide variety of application fields including probiotic-based products.

Consumer Supplementary Benefits from Prebiotics, Probiotics, and Synbiotics in Food Packaging

The rising popularity of prebiotic, probiotic, and synbiotic products has made them commercially accessible in a broad range of products and a recent study revealed a threefold increase in the consumption of probiotics on the global market [1–3, 13, 16]. Due to this, several companies now regard prebiotic, probiotic, and synbiotic products as very appealing business potential.

One emerging trend is the addition of probiotics, prebiotics, and synbiotics to food products [13, 16, 119]. Studies dating back to as early as the eight century show the use of probiotics in milk products as a treatment for lactose intolerance, and in the treatment of irritable bowel syndrome [120]. Supplementing probiotics in dairy products has also shown a marked reduction in cholesterol levels in people. In addition, there was a significant reduction in side effects through probiotic consumption as compared to commercially available pharmaceutical products [41].

Hereinafter, food products like yogurt, which contains probiotics, have been successful in reducing the bacterial load of pathogenic species, particularly Enterobacteria, in the intestines and increased the activity of enzymes like galactosidase [41]. Probiotics from the yeast family Saccharomyces can reduce the frequency of watery diarrhea [121]. Probiotics are also known to increase the production of antibodies in the body, along with interleukins, which help in the prevention of viral infections [122]. Another emerging use of probiotics is seen as a prophylactic measure in cancer therapies. Many probiotics are found to prevent the growth of cancer by occupying the surface of the colon in animal models [123]. Some strains of *L. rhamnosus* also help in inducing apoptosis and thus preventing cancerous growth [124].

Probiotic strains are also known to secrete microcins and these are compounds that prevent pathogenic strains from cellular invasion. They act by binding to the siderophore receptors and block the enzymatic activity of ATP synthase, DNA gyrase, and RNA polymerase. This ultimately leads to a reduction of pathogenic cell load [125]. Some of the health benefits offered by the use of probiotics are summarized in Table 1.

Along with the supplementation of probiotics, the use of prebiotics is popularized to increase the efficiency of probiotic strains. Prebiotics help in the growth of "good bacteria" probiotics, since many of the compounds classified as prebiotics are nutritive supplements for the probiotics [130]. This allows for the proliferation of these bacteria and ultimately causes a reduction in the growth and development of the harmful pathogenic microbes in the intestines. Thus, this helps in the maintenance of healthy gut microflora.

Prebiotics also help in the absorption of minerals and other beneficiary products in the intestines [131]. Most of the prebiotic compounds can also be used as nutritive supplements. For example, supplementing yogurt with fructooligosaccharides (FOS) makes the product sweeter and reduces its calorific value [131]. Supplementation of prebiotics like inulin is already commercialized in a wide variety of dairy and baked products. Inulin is a soluble fiber that has been associated with belly loss and can thus serve in weight management products.

Seeing the immense benefits of pre- and probiotics, the use of their mixture, termed synbiotics, has become relevant in recent years. One of the most well-known natural synbiotic products is breast milk [132]. The prebiotic component includes oligosaccharides while the probiotic component mostly includes lactic acid bacteria. The health benefits of infants consuming breast milk are well known and include the prevention of diarrhea. Diarrhea can also be prevented by the consumption of fruit juices supplemented with synbiotics. Synbiotics can also be used to help reduce the effects of inflammatory bowel syndrome and constipation. Some of the health benefits offered by the use of synbiotics are summarized in Table 2.

In addition to the commonly used bacterial strains, researchers are identifying new strains that can serve as "next-generation" probiotics [135]. One such strain, *Akkermansia muciniphila*, is now commercially used as a synbiotic with other bacteria and inulin. This synbiotic preparation helps in improving the glucose levels in the body and is especially effective in type 2 diabetes patients.

Although there are immense health benefits to harness from the supplementation of probiotics, prebiotics, and synbiotics in food products, it is not widely commercialized yet. This is because of the various challenges in the production of these products and in the maintenance of their shelf life [136, 137].

Table 1 Health benefits offered by the use of probiotics

Probiotic strain	Health benefit	Reference
Bifidobacterium infantis	Useful for increasing the CD103(+) dendritic cells (DCs) in the lamina propria. This helps in reducing the severity of dextran sulfate sodium-induced colitis	[126]
Combination strains (*Streptococcus*, *Thermophilus*, *Bifidobacterium*, and *Lactobacillus*)	Improved insulin sensitivity, total fatty acid content, serum alanine aminotransferase (ALT) levels, and the histological spectrum of liver damage in mice	[127]
Combination strains (*Bifidobacterium bifidum*, *B. lactis*, *Lactobacillus acidophilus*, *L. brevis*, *L. casei*, *L. salivarius*, and *L. lactis*)	Acts on neutrophils by modulating their resting burst, gut permeability, or inflammatory markers	[128]
Lactobacillus reuteri and *L. rhamnosus*	Effective treatment for bacterial vaginosis	[129]

Table 2 Health benefits offered by the use of synbiotics

Synbiotics	Health benefit	References
Fermented milk, made by using *Bifidobacterium breve* and *Streptococcus thermophilus* and supplemented with a prebiotic mixture—short-chain galactooligosaccharides/long-chain fructooligosaccharides (scGOS/lcFOS 9:1)	Caused a reduction in the clinical symptoms of diarrhea, such as severity and incidence in rotavirus-infected rats	[133]
Lactic acid bacteria (LAB) supplemented with polyphenol-rich wine grape seed flour	Inhibited high fat-induced obesity and inflammation in high-fat diet-induced obese mice via alterations in intestinal permeability and adipocyte gene expression	[134]

Many of the probiotic strains used can be lost due to unsatisfactory packaging of food products and poor temperature control in storage [138]. Prebiotics are also susceptible to degradation in higher temperatures and changes in pH; thus, it is of utmost importance to regulate their production and assure quality checks [31, 41, 139]. Another challenge stems from the overuse of bacterial strains in food products which can cause discomfort including bloating and stomach aches [41].

Many obstacles posed by pro-, pre-, and symbiotic products did not impede the development of edible food packaging. This is shown by the level of development of modern technologies and the many research conducted to assist the development of edible food packaging by choosing polymers, additives, and modifications to enhance their properties [140]. Due to the fast expansion of the food business, the number of food products launched to the market has expanded significantly; thus, edible packaging must be created with food substrates in consideration [140]. In other words, a key issue in the development of edible food packaging is the selection of the appropriate packaging materials and formulations for specific food products [140]. Moreover, several studies have shown very gratifying outcomes in resolving present challenges in food packaging by choosing the appropriate packaging materials and formulations for edible food packaging [141, 142], and this has boosted the global acceptance of edible food packaging [54].

Future Perspectives and Conclusions

Consumers are increasingly concerned about the health effects and nutritive qualities of food products, and they perceive various health benefits related to pre-, pro-, and synbiotics. Pre-, pro-, and synbiotics are becoming more and more popular. The growing interest and popularity in the pre-, pro-, or synbiotics motivate further development of processed food, through which manufacturers produce goods fortified with pre-, pro-, or synbiotics to support the growing demand. Hence, more and more new food products with added pro- or synbiotics will be seen at the supermarket shell in the coming years. However, the utilization of these pro- and synbiotics had several technological or processing barriers, mainly viability and functional instability in the prepared functional food. Hence, various manufacturing techniques have been practiced to tackle instability issues of probiotics including encapsulation and the use of edible films or coating as a carrier system. In this context, the development of edible films or coating incorporated with pre-, pro-, or synbiotics is increasingly important novel technology for food scientists, as well as food industry experts. Therefore, there is no doubt that there will be more research work on this interesting concept in the coming years, which will be focusing on various raw materials, manufacturing techniques, stabilities studies, etc. Additionally, future work should focus on the different encapsulation methods to incorporate the pre-or probiotics in existing biodegradable or edible coating materials, the effect of a combination of pre- and probiotics (synbiotics) on the mechanical properties of the packaging film, the combination of different packaging materials with required pre-or probiotics or vice-versa, viability and bioavailability studies of incorporated biotics in packaging film or coatings need to determine in order to confirm the health-promoting ability of incorporated fiber or bacteria. Importantly, sensory analyses and consumer preference need to be evaluated for the new functional products packed with edible film or coating incorporated with pre-, pro-, and synbiotics.

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Papers of particular interest, published recently, have been highlighted as:
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