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Climate-Conscious Food Preserving Technologies for Food Waste Prevention

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Abstract. Global food production is responsible for around 26% of greenhouse gas emissions caused by human activities. Notably, 6% of these emissions are caused by unconsumed food. Both traditional and current climate-conscious technologies for food preservatives that assure food waste reduction are discussed. This review investigates the potential of smart packaging biosensors and natural antimicrobial agents in fostering environmentally friendly, cutting-edge food systems. Specifically, it highlights the studies that explore the use of natural antimicrobial agents of calcined corals in active packaging systems for storing milk. The finding revealed that this method had a significant impact on maximizing the shelf life of fresh food. Furthermore, this review discusses the concept of smart packaging of food, focusing on biopolymer-based nanocomposites and biosensors, which have gained increasing attention in the food industry due to concerns about food safety and quality. The review also examines the efforts of the United Arab Emirates (UAE) to combat food waste through the initiatives such as UAE Food Bank, Winnow, and Ne'ma which is the national food loss and waste project. These technologies and practices have the potential to guarantee food safety, preserve quality, and reduce waste, but there are still issues with cost, biocompatibility, and consumer acceptance.

Keyword. Climate-conscious food, Food preservatives, Natural antimicrobial agents, Smart Packaging, UAE food safety.

1 Introduction

Globally, food production accounts for approximately 26% of the human-caused greenhouse gas emissions, with 6% is from unconsumed food [1]. Food that is produced does not reach consumers due to various reasons, such as spoilage or inefficiencies in the supply chain which results in the loss or waste of resources, time, energy, and effort. This decreases the effective yield of the food production system and thus reduces the amount of food accessible for consumption [2]. Unsustainable production and consumption habits are largely responsible for the three major problems of biodiversity loss, pollution, and climate change. Goal 12 of SDGs [3] strives to address this issue by fostering sustainable consumption and production practices, which are critical for supporting the livelihoods of both present and future generations. Moreover, food waste due to the supply chain is mainly caused by traditional food technologies. For a considerable time, conventional meat production has been associated with high greenhouse gas emissions due to manure and enteric fermentation. Practical difficulties such as resource-intensive operations, pollution, the prevalence of antibiotics in animal products, and the advent of Zoonotic illnesses have afflicted the industry. Diet that primarily consists of meat has also faced criticism for using inefficient production techniques and generating substantial carbon footprint [4].

Furthermore, traditional food preservation and processing techniques frequently necessitate substantial amounts of energy and may contribute to greenhouse gas emissions due to fuel consumption.

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These traditional methods may increase food spoilage and waste, resulting in additional carbon emissions [5]. In addition to food preservation and processing techniques, conventional irrigation and transportation practices have a huge negative environmental impact. Using conventional irrigation techniques, like flood irrigation, could cause a considerable loss of water and may add to soil erosion and damage. Such consequences might cause a decrease in the amount of carbon that is stored in the soil and lead to reduced carbon sequestration, thereby contributing to climate change. When water supplies are uncertain, irrigation cannot be considered sustainable. This is particularly true in regions that suffer from water scarcity. In such locations, the primary focus of irrigation development should be on reducing water consumption to the minimum amount needed for crops [6]. Furthermore, due to fuel consumption, conventional methods of shipping and delivering food can result in significant emissions of greenhouse gases, especially when long-distance transportation is required. Conventional transportation practices might also cause food spoilage during transit, resulting in food waste [7].

The effects of climate change have been the major threat to global food security in recent years. Climate change reduces food production, leading to increased food prices. Climate change hazards are also exacerbated by the expanding global population [8]. Therefore, we need to explore new advancements in food production systems to minimize the environmental impacts and food waste. Meat substitutes are foods that imitate the visual, texture, and chemical properties of traditional meat products. Numerous customer testimonials have praised contemporary meat replacements for their ability to satisfy consumer desires by mimicking the look, flavor, and texture of traditional meat. Addressing customer concerns about the environmental effect, food waste, and animal welfare issues associated with conventional meat production is another important goal [9]. Precision agriculture is an advanced technique that utilizes a variety of devices, such as sensors, drones, and other tools, to gather information regarding weather conditions, soil conditions, and crop growth. This technology enables farmers to enhance resource management, minimize waste, and boost crop productivity [10]. Plastic packaging used for many food products is a major source of pollution in the food processing industry. Biodegradable packaging produced from natural materials such as plant fibers or starch can be a significant step toward waste reduction [11]. In terms of packaging, advancements in packaging design have the potential to decrease the weight and size of food items, resulting in lower transportation costs and emissions [12].

This review paper is to provide a detailed overview of climate-conscious food technologies for preventing food waste and various technologies available to address this critical challenge. However, these technologies were focused on food preservation. This review paper will fill up the gap by assisting researchers, policymakers, and industry professionals in better understanding the latest advancements in this field and identifying areas where further research is required. The following part will address historical, present, and recent innovations methods and technologies in climate-conscious food preservatives for preventing food waste. Additionally, the limitations and current challenges for each perspective, as well as food safety concerns in UAE, will be reviewed and defined.

2 Traditional food waste prevention technologies

Climate-conscious techniques have been used for millennia to prolong the shelf life of food and decrease food waste. The approaches, such as fermentation, drying, smoking, and canning, delay or prevent food from spoiling, hence prolonging its shelf life and availability. Traditional fermentation is a food preservation method that helps to reduce food waste. This time-honored technique of food preservation employs naturally occurring microorganisms to convert sugars within foodstuffs, generating lactic acid, alcohol, and other compounds that contribute to food preservation. As a result, the life span, taste, and nutritional content of the food are enhanced. Fermented foods like kimchi, sauerkraut, kefir, and yogurt have been essential to human nutrition for ages and will likely continue to be consumed frequently [13]. Traditional drying is another food preserving method that can aid in preventing food waste. By removing moisture from food products, drying stops the growth of bacteria and other microbes that cause spoilage. This method has been utilized for centuries to preserve various foods, such as fruits, vegetables, meats, and grains [14].

Traditional smoking is also a food preservation method that can assist in reducing food waste. For millennia, smoking has been used as a food preservation technique, particularly for meats and fish. Food is exposed to smoke from the combustion of wood or other plant resources, which provides a barrier that prevents bacteria and other microbes from replicating on the food's surface. Additionally, the smoke bestows a distinct flavor to the food, making it a preferred option for a variety of culinary applications [15]. Traditional canning is the fourth environmentally friendly food preservation method that aids in minimizing food waste. In canning process, food is sterilized by heating it to a high temperature and sealing it in airtight containers to prevent bacteria and other germs from causing food to spoil. The sealed containers restrict oxygen access, preventing food spoilage and enabling long-term storage at room temperature [16].

Traditional food preservation methods have several benefits, including reducing food waste, less energy consumption than modern techniques, and increasing food security by providing a more stable supply during times when fresh food is unavailable. However, these methods have limitations, such as the inability to accommodate mass production and distribution, potential inconsistencies in results due to environmental factors, and health hazards associated with improper execution, for instance the risk of botulism in improperly canned foods. Consequently, traditional existing technologies had to be updated and replaced by modern food waste prevention technologies.

3 Emerging food waste prevention technologies

Techniques for managing food waste focus primarily on reducing waste. Thus, it is critical to draw attention to recent developments in food waste management. The conventional food waste management techniques are as follows [17].

a. Insect-based bioconversion: Break down of food waste by insects (mealworms, crickets, black soldier flies) and turning it into high value products from their excrement
b. Incineration: It can recover resources, generate electricity, and minimize the quantity of waste that needs to be disposed of, but because of the high nitrogen dioxide emissions and the abundance of produced dioxins, it will also exacerbate acidification, eutrophication and be hazardous to human health.
c. Landfill: Low-cost, but it will pollute the environment, cause climate change because of greenhouse gases, take up a lot of space, contaminate groundwater sources, and deteriorate soil quality.
d. Composting: Prevents the leaching of waste underground and aids in the production of field-ready manure. It can cause carcinogens if improperly handled.
e. Anaerobic digestion: Low environmental impact.
f. Animal Feeding: Direct feeding or the conversion of food waste into animal feed. Animals may be harmed by the variance in food waste and food contamination found in different batches.

3.1 General emerging food waste prevention technologies

High-pressure processing (HPP) is a current food preserving technology that can help to prevent food waste. HPP includes exposing food to high pressure, which kills microorganisms that cause spoilage while preserving the nutritional value and flavor of the food. This technology is effective for perishable foods such as meats, seafood, and juices, to prolong their shelf life while maintaining the quality [18]. Modified atmosphere packaging (MAP) is another recent food preservation technology that can assist reduce food waste by modifying the atmosphere inside the food package, typically by increasing the amount of carbon dioxide or nitrogen and decreasing the amount of oxygen. The growth of microorganisms that lead to food spoiling can be slowed down by this altered environment, extending the shelf life of the food. MAP is especially useful for fresh vegetables and fruits, meats, and bakery products [19].

Next, vacuum packaging is a food preservation technology that works by eliminating air from the food package, generating a vacuum, and then sealing the box. This procedure can slow down the growth of the microorganism that led to food spoilage. Vacuum packaging is very useful for fresh meats, fish, and cheese, as well as processed foods such as snacks and coffee [20]. Moreover, irradiation is a recent food preservation technology, but its climate-consciousness is still being debated due to some environmental concerns. Irradiation is exposing food to ionizing radiation, which destroys bacteria and other germs that cause deterioration. This method has the potential to prevent foodborne illness while also extending the shelf life of food. Irradiation is especially beneficial for fresh fruits and vegetables, meats, poultry, and spices [21]. Current food preservation methods have several advantages, including increased food safety by neutralizing harmful microorganisms and enzymes, extending shelf life to minimize waste, and improving food quality, thereby enhancing its value. However, the drawbacks of these methods are potential adverse effects on the environment due to the production of radioactive waste from irradiation, high energy consumption that contributes to greenhouse gas emissions, and high costs for small-scale food producers. Therefore, it is necessary to upgrade current existing technologies and replaced them with newly developed food waste prevention technologies that prioritize climate consciousness such as incorporation with natural antimicrobial agents and biosensors for smart packaging, which aim to reduce the environmental impact of preservation methods while also promoting food industry sustainability.

3.2 Food packaging

In addition to food waste, food packaging materials are also regarded as municipal solid waste, particularly plastics-based packaging materials that are difficult to degrade and cannot be composted. The widespread use of plastic in food packaging considerably increases environmental pollution because the plastic can break down into smaller fragments (micro- and nano-plastics), which can infiltrate the food chain and have an impact on all trophic levels, including humans [22]. Consumer awareness and safety concerns drive the evolution of food packaging applications due to the migration of packaging material into the food. For instance, when using materials like paper and plastic for food packaging, additives including plasticizers, antioxidants, UV stabilizers, colors, and printing inks may contaminate the packed food. In addition, monomers, and oligomers of the materials as well as additives needed for polymerization may migrate into the food. The usage of metal packaging, such as food and beverage cans, raises the risk of corrosion from high-salt or acidic food items. Heavy metals can also be found in food packaging materials. In short, Food safety is impacted by packaging materials due to chemical migration, inadequate barrier qualities, packaging failure, and loss of seal integrity [23].

Thus, package optimization enters the picture, which is the use of smart packaging to contain, communicate, and protect your items as they are moved from a manufacturing plant, warehouse, or fulfillment center to their destination. Biodegradable packaging materials are preferred because they decompose and can be degraded by soil microbes. This resulted in the development of intelligent packaging, active packaging, and smart packaging, as well as their corresponding applications on the global market. An intelligent packaging system monitors environmental conditions and provides information on the quality of packed goods, whereas an active packaging system includes active components into packaging to increase food quality and shelf life. The usage of "smart packaging" systems can keep track of physicochemical factors like environmental conditions and prevent microbial changes. With the use of cutting-edge technology, active packaging systems can incorporate active ingredients, such as antioxidants, antimicrobials, carbon dioxide scavengers, ethylene scavengers and oxygen scavengers, into the polymeric packaging matrix to maintain and extend the shelf life of food. Active food packaging offers significant promise for maintaining the quality and safety of food products, particularly oxidation-sensitive foods. Next, the level of freshness of the product and its environmental influences, such as temperature, pH level, and gas, are indicated and tracked by an intelligent packaging system during transportation and storage. When there are any internal or exterior changes, the packaging's sensor can detect them and alert the consumer to the situation by giving audio and visual data. Integrating sensors (biosensor, gas sensor), indications (temperature, leakage freshness, pathogen, color), or radio frequency identification systems is the core component of intelligent packaging. All the packaging materials mentioned must be affordable in relation to the value of the product, consumer-acceptable, and environmentally friendly [24].

3.2.1 Natural antimicrobial agents

Food spoilage is largely caused by microbial contamination throughout the food chain, which in turn contributes to food waste, economic losses, and food insecurity. Synthetic chemical preservatives are routinely used to prevent microbial spoilage and prolong the shelf life of food products. However, due to concerns about their negative health effects, consumers and researchers are not recommending their use. As a result, naturally occurring antimicrobials have piqued the interest of food manufacturers and researchers because of their non-toxic nature. These preservatives are naturally derived from numerous sources, such as plants, animals, and microbes, and can be extracted using advanced techniques. Nisin, essential oils, and natamycin are a few examples of natural preservatives with potent antibacterial activity. However, some developing nations have not yet regulated these natural preservatives [25].

The introduction of antimicrobial compounds into food packaging materials is gaining popularity in the packaging industry due to its ability to reduce microbial surface contamination, improve food safety, and prolong shelf life. Different types of packaging materials can be combined with various antimicrobial compounds. However, due to scarcity and safety concerns, there has been an increase in the demand for natural food ingredients, resulting in the substitution of chemical additives with observed safer natural compounds. Current research is mostly focused on utilizing natural antimicrobials obtained from biological sources in food packaging, like bacteriocins, phytochemicals, and enzymes. These natural antimicrobials can be added to packaging materials to provide antimicrobial properties [26].

Natural substances that are biologically produced, such as enzymes, plant extracts, and bacteriocins, can be used in antimicrobial packaging. Table 1 lists a few examples of natural antimicrobials that could be used for food packaging [26]. A study was conducted to investigate the incorporation of natural antibacterial compounds of calcined corals in an active packaging system for storing milk [27].

Table 1. Possible natural antimicrobial agents and biopolymers that could be used in food packaging [26].

Types	Biopolymers and antimicrobial agents
Lipid based coatings	Carnauba wax, beeswax, sugar cane wax, bay berry wax, rice bran wax.
Derivatives of polysaccharides	Chitosan, starch, pullulan, cellulose based paper, natural gums, fatty acids, carrageenan, chitosan, alginate.
Plant/ spice extracts and plant volatiles	Cinnamaldehyde, allyl-isothiocyanate, eugenol, terpineol, linalool, thymol, pinene, carvacrol, allicin, grape seed extract, grapefruit seed extract, hop beta acid, rosemary oil, brassica erucic acid oil, oregano oil, basil oil.
Chelating agents	Ethylenediaminetetraacetic acid (EDTA)
Enzymes/ bacteriocins/ proteins	Soy-protein isolate, corn-zein, whey-protein isolates, peanut-protein, wheat-gluten, collagen/gelatin, milk-proteins.

The study produced a variety of composite films made of low-density polyethylene/ nylon that contain calcined corals (LL/ NY-CORALS). The aim was to investigate the relationship between the number of calcined corals and the physical characteristics as well as the antibacterial properties, particularly the suitability for milk storage. The findings revealed that increasing the number of calcined corals decreased the crystallinity of the composite films without affecting thermal stability or permeability. Notably, LL/NY-CORALS packaging greatly increased the time it took for bacteria to begin growing while slowing down the growth cycle of bacteria in the stored milk with the LL/NY-CORALS 0% film having the highest number of surviving microorganisms of all analyzed composite films. The number of surviving microorganisms decreased as the content of composite films calcined corals increased. Therefore, LL/NY-CORALS composite films have the potential to be employed as food packaging material, potentially extending the shelf life of fresh foods [27].

3.2.2 Biosensors for Smart packaging

Smart packaging is a comprehensive concept that encompasses both intelligent and active packaging. Intelligent packaging can detect external and internal changes in a product and communicate with an external interface, whereas active packaging can respond to these changes by releasing or absorbing substances to extend the shelf life and preserve the freshness of the product. The ultimate purpose of smart packaging is to increase product safety, and traceability throughout the supply chain, and provide quality information to consumers. Active packaging is an alternative to traditional packaging and can maintain the high quality and freshness of food products by embedding different components that can release or absorb substances to prevent spoilage [28].

The idea of intelligent food packaging, which utilizes biosensors and biopolymer-based nanocomposites, has been gaining traction in the industrial sector due to concerns about food quality and safety. The detection layer in biosensors consists of biological materials like antibodies, enzymes, antigens, nucleic acids, and phages. There are a few examples of food packaging integrated biosensor systems [29]. Despite the fact that many biosensors have uses in the health and environmental sciences, not all of them are appropriate for food packaging due to factors such as sensitivity, microstructure, specificity, processing cost, and stability. Several biosensors have been documented and tested specifically for food-related uses, including gas detection sensors, microfluidics and fluorescent sensors, electrochemical/imprinted biosensors, thermal biosensors, and immunosensors. Table 2 summarizes the most often discussed biosensors for intelligent food packaging [30].

Prompt detection of foodborne pathogens is critical for ensuring food safety. A microfluidic biosensor was studied for real-time and precise *Salmonella* detection in a study [30]. The biosensor integrated fluorescence labeling, smartphone video processing, and immunomagnetic separation. The target bacteria, which produced magnetic bacteria, were initially concentrated and separated using immune magnetic nanoparticles. Subsequently, immune microspheres fluorescently labeled magnetic bacteria, resulting in fluorescent bacteria. Lastly, fluorescent bacteria were continually fed into the microfluidic chip using a microscopic smartphone-based fluorescent system, and an app using an inter-frame difference algorithm calculated the desired bacteria number by counting the fluorescent spots online. This proposed biosensor could detect *Salmonella typhimurium* concentrations quantitatively under optimal conditions, with a lower detection limit of 58 CFU/mL. The modification of this could detect different foodborne infections by using various fluorescent materials.

The development of eco-friendly food systems has been considerably aided by recent research on the biosensors in smart packaging and natural antibacterial agents. These innovative techniques contribute to a greener food industry by encouraging sustainability, reducing waste, and guaranteeing food safety. However, there are some difficulties in implementing biosensors in smart packaging and natural antimicrobial agents to promote sustainable food systems. Obstacles for biosensors include the high costs of development and implementation, potential issues with sensor accuracy and precision, and the integration of these sensors into the existing supply chain. Moreover, the biocompatibility and biodegradability of these sensors remain major concerns. As for natural antimicrobial agents, their limitations include their varied effectiveness depending on origin and concentration, potential interactions with food components that could affect their performance, and regulatory issues regarding their safe incorporation into food products. Furthermore, the likelihood of scaling up the production of these natural agents as well as consumer acceptance must be considered. In summary, while these technologies hold great promise for environmentally responsible food systems, overcoming these hurdles will be essential for their widespread adoption and long-term success.

3.2.3 Nanocomposites in food packaging

As the applications of nanotechnology have grown, it has been discovered to be a promising technology for the food packaging business. With its increased barriers, mechanical, thermal, and biodegradable qualities, as well as applications in active and intelligent food packaging, it has demonstrated satisfactory abilities as food packaging materials. Silver, zinc oxide, and magnesium oxide are a few nanofillers that exhibit antibacterial or antioxidant properties. These nanofillers inhibit or delay the growth of microbes in polymer or biopolymer matrices, which lowers the risk of food deterioration [31]. Gold nanoparticles (AuNPs) are employed as the novel materials for the nanopackaging industry due to their medicinal and antibacterial properties as well as their inert nature. [32]

Table 2. Types of biosensors or sensors for intelligent food packaging [30].

Type of biosensor	Types of Biosensors	Analytes	Detection limit	Detection time
Microfluidic and fluorescent biosensor	The fluorescent biosensor of Magnetic type	*E. coli* 0157:H7	14 CFU/mL	2 h
	Nanoclusters of fluorescent Ag +	Ammonia	336 nM	60 min
	Microfluidic sensor poly(dimethylsiloxane) coated	H_2O_2	5 nM	30 min
	Fluorescence biosensor iron coated	*Shigella* spp.	10^2 CFU/mL	20 min
	Microfluidic biosensor	*Salmonella typhimurium*	10^5 CFU/mL	15 min
Electrochemical biosensor	Xanthanin biosensor	Xanthanin	0.1 μM	–
	Electronic transistor CNT	*Salmonella Infantis*	10^2 CFU/mL	1 h
	SWCNT-based biosensor	*Y. enterocolitica*	10^5 CFU/mL	30 min
	Potentiometric aptasensor	*Salmonella typhimurium*	10^1 CFU/mL	10 min
	Amperometric biosensor	L-malic acid	2.9×10^2 g/L	2 min
Gas biosensor	Microcantilever sensor	H_2S	1 ppm	2 h
	Field-effect transistor poly(3-hexyl thiophene) organic	NH_3	100 ppm	6 min
	FET-type sensor	SO_2	10 ppm	3 min
	Pd coated SnO2 nanofiber	H_2	0.25 ppm	40 s
	Carbon codoped acetone sensor	Acetone	10 ppm	100 s

Numerous Gram-positive and Gram-negative microorganisms have been studied, with *E. coli* being the most contentious. Thus, the use of AuNPs as antibacterial agents for high-end, luxurious goods like caviar is strongly advised. *et. al.* [33] employed polystyrene and active agents to fabricate active antifungal packaging material. Thyme extract was used as a reducing agent in the manufacture of zinc oxide nanoparticles. Zinc oxide nanoparticles were impregnated in polystyrene to create the nanocomposite film. According to the findings, nanocomposite films were extremely resistant to the fungus such as *Pencillum* spp., *Nigrospora oryzae*, and *Chaetomium oryzae*. Besides, Jayakumar *et. al.*, [34] created a composite polymeric film made of starch and PVA with the addition of ZnO nanoparticles, jamun (*Syzygium cumini*) and nutmeg (*Myristica fragrans*) extracts to provide it additional desirable qualities for use in food packaging. It was discovered that the nanocomposite film changed color in response to pH changes. Additionally, to preserve the quality of raw meat, biopolymer films based on chitosan, potato protein, linseed oil, and ZnO NPs were produced [35]. Results showed that the film demonstrated good tensile strength, elasticity and moisture barrier [35]. Throughout history, various types of packaging materials have been used, but bio-nano composite materials have proven to be the most effective because they have been developed with vital properties like biocompatibility, antimicrobial activity, biodegradability, and barrier properties. Sensory components can be included into the bio-nanocomposite material to advance active and intelligent packaging, which is a type of packaging utilised particularly for long transportation and massive packing.

4 Food waste prevention in the UAE

As the UAE will host COP28 in Abu Dhabi at the end of 2023, preventing food waste in the country is crucial to promoting sustainability and responsible consumption. The country has been actively working to reduce food waste, including implementing public awareness campaigns, supporting food redistribution programs, and promoting sustainable corporate practices [36, 37]. The UAE hopes to contribute to worldwide efforts to reduce food waste and improve environmental conservation by focusing on minimizing waste in the food supply chain and developing a culture of mindful consumption [38].

4.1 The UAE food bank

The UAE Food Bank was established on 4th January 2017 as part of the Mohammed bin Rashid Al Maktoum Global Initiatives (MBRGI). Providing food to those in need and minimizing food waste are two of its main objectives. The Food Bank collaborates with local authorities, and both local and international NGOs, to establish an efficient system for packaging, distributing, and storing surplus fresh food from restaurants, hotels, and other food institutions. The goals of minimizing food waste include saving money on the high expenses of discarded food, which total AED 282 million per year in Dubai and about 13 billion AED across the UAE.

Additionally, the UAE contributes to sustainable development for a variety of purposes, including energy production, by recycling inedible food [36]. Efforts to repurpose food instead of discarding it help to minimize carbon emissions, pollution, and climate change. These initiatives also aim to save the UAE's natural resources for future generations by conserving soil and water. Moreover, by encouraging the use of organic fertilizers made from surplus food, they contribute to reduce chemical pollution caused by chemical fertilizers [36].

4.2 Winnow

The hospitality industry confronts yearly food waste expenditures of more than $100 billion, with kitchens squandering up to 20% of the food they purchase, frequently equalling their whole net profits [37]. The root of this problem is chefs lacking the necessary tools to precisely monitor, measure and manage waste. Better management results from accurate measurement, and smart data use can increase kitchen productivity. Winnow creates technology that gives chefs more visibility in their kitchens, allowing them to make more educated decisions that decrease food waste and costs. This allows chefs all around the world to focus on cuisine inventiveness. By enabling smarter kitchens, Winnow helps the hospitality and food service industries reduce food waste. Winnow allows kitchens to properly track their waste. Winnow Vision, our AI-enabled solution, enables kitchens to automatically track food waste, saving time and money. In order for the computer to learn and recognize foods dumped in the trash, the system takes photos of wasted food as it is thrown out. As food is thrown away over time, this leads to automatic data capture, improving data accuracy and usability. The process is streamlined by the Winnow Waste Monitor, which is user-friendly and has a digital scale and connected iPad. Staff employees dispose of food in any bin as usual, with the weight noted. The user then selects the reason for disposal and recognizes the item or dish on the tablet [37].

4.3 UAE future directions through food waste prevention

By launching the National Food Loss and Waste Initiative, Ne'ma, the UAE has taken a big step towards addressing the issue of food loss and waste. By implementing sustainable practices in the food industry and raising consumer awareness, the initiative seeks to reduce food loss and waste throughout the UAE. According to the Ministry of Climate Change and Environment, food waste in the UAE is estimated to be around 3.27 million tons per year, which is equivalent to around 13% of the total food produced in the country [39]. The Ne'ma program entails cooperation between public and private sector organizations as well as consumers to develop a sustainable food system in the UAE. The project is designed to benefit the environment and the economy by lowering greenhouse gas emissions, conserving natural resources, and improving food security in the country. The UAE's National Food Loss and Waste Initiative, Ne'ma, serves as a model for other countries to follow in their efforts to tackle food waste.

5 Conclusion and future directions

The use of smart packaging biosensors and natural antimicrobial agents has shown promising results in the development of sustainable and ecologically friendly food systems. The United Arab Emirates' attempts to eliminate food waste through numerous projects demonstrate the country's commitment to sustainability and ethical consumption. Nonetheless, issues such as cost, biocompatibility, and consumer acceptance must be addressed before these technologies and practices can be widely adopted. To achieve a more sustainable and ecologically responsible future, government agencies, the commercial sector, and consumers must continue to collaborate on research, development, and collaboration. To that aim, ongoing research into emerging technologies, as well as the dedication of all stakeholders, will be critical in overcoming obstacles and realizing the full potential of these innovative solutions.

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