Chapter

Food Contamination Detection

Cheima Ben Hattab

Abstract

Trendley, consuming the freshest vegetables and fruits is the most consumer's interest. However, the global issue of food waste has a negative impact on the planet and poses significant risks to natural, human, and economic resources. Therefore, the necessity to reduce food waste is a crucial step towards fostering cooperation and exchange among stakeholders throughout the entire food chain. This involves raising awareness, improving data quality, monitoring, and implementing preventive measures in practice, all dedicated to ensuring sustainable production and consumption patterns. The aim of this research article is to focus on reducing waste in contaminated food and exploring how technology can be utilized to detect and trace the state of food. The investigation targets two key aspects: food spoilage and food safety. The primary method employed for this purpose is utilizing smart packaging technology, integrating smart coatings into the RFID system to enhance food safety traceability, shelf life, and consumer convenience.

Keywords: food freshness, smart packaging, smart coating, intelligent packaging, RFID, tag antenna sensor

1. Introduction

Recognizing that, as of 2023, there was an average of 74 kg of food waste per person worldwide, accounting for about 1.3 million tons of food wasted globally. Even when it is not consumed, one billion tons of food produced worldwide ends up in the trash. The inquiry where it is applicable the food waste we found it everywhere the main areas are primary production, processing manufacture, retail and households [1]. The amount of food that is lost and wasted annually, according to FAO estimates, could feed 1.26 billion hungry people. It is important to address the issue of spoilage as it poses a risk to consumer health across all age groups, including both elderly people and infants as consuming contaminated food can lead to illnesses. One contributing factor to the presence of substances in food is the preparation and serving of food, dishes and meals without proper control within the food service industry. These practices can be responsible, for dermatological and stomach ailments. At that point, the global problem of food waste and its negative effects on regular, human, and financial resources is resolved. Unless a variety of studies suggest establishing a waste management system to convert food waste into daily resources, achieving sustainability goals will remain challenging. This requires cooperation and exchange of ideas among performers at all levels of the hierarchy, exposing problems, improving the standard of information, verifying it, and carrying out corrective measures. Encouraging customers to reduce food waste by providing them with effective mindfulness raising data is a major component of our research. There are natural components that can potentially be toxic to consumer; however, it is possible for feeds and foods to become contaminated with mycotoxins prior to harvest, during the interval between harvest and drying and during storage. The purpose of this research is to evaluate and manage food packaging materials, technologies, and techniques to reduce the risks associated with contaminants and harmful substances. By providing instruments and intelligent technologies that can facilitate the maintenance of food safety, the emphasis is on enhancing food safety protocols. The twenty-first century has seen a myriad of concerns related to food quality, including malnutrition, the occurrence of hazards in alimentary products, and sale/commercialization (all varieties) that are considered fraudulent. Significant effects on human health have prompted regulatory authorities like the FAO and Codex Alimentarius to develop interventions. However, with rapid urbanization and a complex nature of the food chain system in specific parts around the world, food hazards as well as fraudulent activities still plague our modern-day era. Foodborne pathogens need to be accurately identified in order to prevent outbreaks of foodborne diseases, which can even lead to death and are normally associated mainly with bacteria that cause these infections. Salmonella, Campylobacter, and enterohaemorrhagic *E. coli* are the most frequent pathogens responsible for serious and sometimes deadly bacterial infections, impacting millions of individuals annually. Most patients develop fever, headache, nausea and vomiting or diarrhea. Salmonellosis outbreaks are often linked to eggs, poultry, and other animal products, while Campylobacter cases are mainly caused by raw milk, raw or undercooked poultry, and drinking water. Enterohaemorrhagic *E. coli* is typically associated with unpasteurized milk, undercooked meat, and contaminated fresh fruits and vegetables. In the realm of food quality monitoring, the emergence of RFID technology has revolutionized the way we approach the challenge of detecting and preventing food contamination.

The smart packaging technology has the potential to be environmentally friendly by using natural and affordable packaging materials, which can help conserve food and minimize its effects on the products we consume. The significance of this study lies in highlighting the importance of employing the smart packaging to ensure preservation of food. Additionally, it emphasizes the use of elements that clarify their influence on the fruit and vegetable composition.

In one hand, this involves the application of smart coating, which adds gloss and decreases evaporation to fruit and vegetables by utilizing a protective material, and on the other hand, attaching an RFID tag to the item can provide real-time information on various parameters, ensuring optimal conditions for the freshness food.

Research on smart coatings for fruits and vegetables has focused on the use of natural sources [2], edible coatings [3], and a combination of lipid, polysaccharide, and protein coatings [4]. These coatings aim to reduce moisture loss, improve appearance, and extend shelf life. The use of biodegradable materials in coatings is particularly promising, as it can reduce the hazards of plastic use. However, further research is needed to address technological, regulatory, and economic aspects, as well as consumer perception and ecological challenges.

Smart packaging innovations have been developed to address various needs in the food industry. These innovations aim to improve food safety, extend shelf life, and enhance the overall quality of packaged products. Active packaging techniques, such as the integration of additives into packaging materials, help protect and prolong the cleanliness and shelf life of products [5]. Intelligent packaging systems, on the other hand, provide real-time feedback on the effectiveness of processed food during transportation and storage, meeting the growing demand for safe and long-lasting food products [6]. Smart packaging technologies also offer potential solutions for the pharmaceutical industry, ensuring the safety and shelf life of medicinal products and supplements [7]. Protein-based smart packaging materials, derived from animal and plant sources, have emerged as environmentally friendly alternatives to traditional nonbiodegradable packaging materials [8]. These protein-based films and coatings have the potential to enhance food safety and quality while reducing environmental issues [9].

Recent advancements in smart food packaging have focused on the development of intelligent materials that can monitor food properties in real-time [10]. These materials are increasingly being made from biodegradable and bio-based polymers, addressing both consumer and environmental concerns [11]. The use of electrospun nanofibers as a platform for pH indicators in intelligent food packaging has also been explored [12]. Additionally, the application of nanomaterials in smart food packaging, particularly in the form of polymer nanocomposites and nanosensors, has shown promise in extending food shelf life and ensuring quality control [13].

Recent research has focused on the use of RFID in smart packaging. Reference [14] discusses the use of electromagnetic simulation tools for designing RFID infrastructure and coverage planning. Reference [15] presents an experimental approach for developing RFID-ready pack-aging, with a focus on improving RFID reliability and designing packaging infrastructure. These studies collectively highlight the potential of RFID in enhancing the functionality and security of smart packaging. In their 2019 review, Tharindu Athauda and Nemai Chandra Karmakar explore pivotal environmental factors influencing food safety and freshness. The review delves into the utilization of smart packaging equipped with sensors capable of detecting alterations in microclimate physical stimuli. Additionally, it provides an in-depth examination of RFID-based sensors within the realm of smart packaging for preserving food freshness, highlighting their current limitations. Reference studies [16, 17] explore the use of RFID in smart container security, with a focus on practical applications and trade-offs.

This study's primary goal is to demonstrate the method by which food can be stored through the advancement of smart packaging technologies, such as coatings that act as active packaging and RFID tags that function as intelligent packaging. These technologies are intended to extend product shelf life and preserve or improve product quality, as well as to identify and track food safety, quality, and freshness along the entire supply chain until it reaches the customer. The main goal is to investigate the ways in which intelligent packaging might improve food safety.

2. Materials and methods

The selection of packaging materials, technologies, and techniques should be suitable for the characteristics and categories of food. Development of an active packaging technology and the choice of coating depend on the specific application, considering factors such as the substrate material, desired properties, environmental conditions, and regulatory requirements. Using the technique of coating that can be applied to various substrates including food products, citing the common types as Polymer Coatings: polyurethane [18], epoxy [19] and polyester [20]. Metallic Coatings: Aluminum [21], Zinc [22], Nickel [23], Chromium [24, 25], Gold [26] Metal-Polymer Coatings: Polymer-Ceramic [27] and Metal-Polymer [28] or edible film based only on naturel and biodegradable materials, to protect the food from external factors that can compromise its quality and safety. Coatings can act as barriers against moisture, oxygen, light, and microorganisms, thereby extending the shelf life of the food product. Additionally, coatings can enhance the appearance, texture, and flavor of the food, making it more appealing to consumers.

The integration of intelligent packaging using RFID technology represents a groundbreaking approach to food packaging and safety management. This technology has the capability to monitor the condition and freshness of packaged food products by providing precise and reliable data.

The data collected by RFID tags can encompass a wide range of parameters, including the food's condition, temperature, humidity, gas level, weight loss (WL) percentage, respiratory intensity (RI), and changes in its external color. This comprehensive data enables stakeholders to gain valuable insights into the quality and safety of the food product throughout its supply chain journey.

By leveraging RFID technology, intelligent packaging systems can effectively monitor and track the condition of food products, ensuring their freshness and quality. This technology has the potential to revolutionize the food industry by enhancing food safety, reducing waste, and improving the overall efficiency of the food supply chain.

2.1 Data collection

2.1.1 External color (EC)

The external color of mangoes is expressed as

$$EC = A / B \tag{1}$$

Where A and B are the internal values of mango.

2.1.2 Respiratory intensity (RI)

The IR is evaluated using Eqs. (2) and (3):

$$RI_{O_2} = \frac{Q_{o_2}.V_{Tommy\ Atkins}.273.10^3}{t.\left(273+T^{\circ}\right).2{,}24w} \tag{2}$$

$$RI_{CO_2} = \frac{Q_{co_2}.V_{Tommy\ Atkins}.273.10^3}{\left(t\left(273+T^{\circ}\right).2{,}24w\right)} \tag{3}$$

With:

RI_{o_2} : Respiratory intensity of Oxygen consumed ($l.mmol^{-1}$).

IR_{co_2} : Respiratory intensity of Carbon Dioxide produced and released ($l.mmol^{-1}$).

Q_{O_2} *and* Q_{CO_2} : Quantity of Oxygen and Carbon Dioxide consumed (%).

$V_{Tommy\ Atkins}$: Volume of fruit (ml).
t: Time (h).
T: Temperature measured (°C).
w: weight of the test substance (g).

2.1.3 Respiratory quotient (RQ)

The RQ represented in Eq. (4):

$$RQ = \frac{RI_{co_2}}{RI_{o_2}} \tag{4}$$

2.1.4 Concentration of ethanol

The general form for the calculation of concentration of ethanol is as follows:

$$C = \frac{(V.w).\Delta A}{\varepsilon.d.V.2.10^3} \tag{5}$$

With:
C: concentration of ethanol $(g.l^{-1.})$
V: test volume (ml)
w: weight of the test substance (g)
d: cell thickness (cm)
ε = extinction coefficient of NADH: nicotiamide adenine dinucleotide (NAD) is reduced to NADH, a compound that absorbs in the ultraviolet.

$$\Delta A = \Delta A_S - \Delta A_T \tag{6}$$

ΔA : the difference in absorbance of the control (ΔA_T) from that of the measured solution (ΔA_S)
So, after calculation, the result for ethanol is:

$$C = 0.1152 \Delta A \tag{7}$$

$$WL(\%) = \frac{Initial\ Weight - Final\ Weight}{Initial\ Weight} \times 100 \tag{8}$$

3. Results and discussion

The external color ratio in Eq. (1) of the fruit increased with time. The enrobed can limit the development of the internal and external color of the 'Tommy Atkins' mango variety during storage. Indeed, after 11 days of treatment, the value of external was −1.6 (enrobed), a decrease of 72% compared to the unrobed sample. The development of fruit color is influenced by the composition of gases in the environment. Eqs. (2) and (3) calculate the respiratory intensity (R I) of O_2 and CO_2 based on several factors. This is important in understanding how fruits respire can help in managing food spoilage and waste. The equation combines these variables to calculate how much CO_2 is produced by the fruit during respiration. This is important for understanding how quickly fruits spoil and how to keep them fresh longer. By evaluating the respiratory intensity of fruits, we can find ways to reduce food waste. If we know how fruits spoil, we can improve storage methods and packaging, which can help keep fruits fresh for longer periods. Eq. (4) is a ratio that compares the amount of carbon dioxide (CO_2) produced by the fruit to the amount of oxygen (O_2) consumed during its packaging. This research is significant because it uses scientific equations to understand fruit respiration. By measuring O_2 and CO_2 production, we can better manage food safety and reduce waste, which is beneficial for both consumers and the environment. Understanding these concepts can help us make informed choices about food consumption and storage. The decrease in oxygen in the atmosphere surrounding the fruit reduces its metabolic activity and ethylene production shown in Eqs. (5)–(7) resulting in the inhibition of external and internal color development in mangoes. We also found that enrobed mango had less attractive external color than unrobed mango, which may affect consumer preference and marketability. Furthermore, the texture and firmness of the fruit were also impacted, with enrobed mangoes exhibiting a firmer consistency, potentially extending their shelf life but compromising immediate palatability. Additionally, the sensory attributes such as taste and aroma were evaluated, revealing that enrobed mangoes had a slightly muted flavor profile, which could further influence consumer acceptance and overall satisfaction. Moreover, the study highlighted the importance of balancing preservation techniques with sensory quality to ensure that mangoes remain appealing to consumers while maximizing their longevity in storage and transport.

The two tables show data concerning the analyses of mango varieties around two types: enrobed and non-enrobed mangoes. The tables involve a comparison of weight loss and the RI of mangoes overtime. Weight loss percentage in mangoes over various concerned time periods, namely, day 1, 3, 6, 8, and 11, is given in tabulated form below **Table 1**. Enrobed mangoes lose less weight compared to non-enrobed mangoes at every time point. This suggests that the coating helps to retain moisture and reduce weight loss. **Table 2** shows the ripeness index (RI)

Day		1	3	6	8	11
Weight loss(%)	Enrobed mango	1.19	3.71	5.51	7 .23	9 .45
	Non-enrobed mango	1.69	4.87	7.28	9.71	12.84

Table 1.
Data analyzing table of weight loss (%) of two treatment types: Enrobed and non-enrobed mangoes over time.

Day		0	1	3	6	8	11
RI of sample	Enrobed mango	2.6	2.4	2.3	1.7	2	1.5
	Non-enrobed mango	2.6	4.3	2.7	3 .6	3 .6	0

Table 2.
Data analyzing tables of respiratory intensity of two treatment types: Enrobed and non-enrobed mangoes over time.

of the mangoes over the same time periods (0, 1, 3, 6, 8, and 11 days). The RI indicates how ripe the mangoes are, with higher values suggesting more ripeness. Enrobed mangoes show a gradual decrease in ripeness, while non-enrobed mangoes have a more fluctuating pattern, indicating that the coating may help maintain a more stable ripeness level. The data from these tables highlight the benefits of using coatings on mangoes. Enrobed mangoes not only lose less weight over time but also maintain a more consistent ripeness level compared to non-enrobed mangoes. This information is valuable for producers and consumers who want to reduce food waste and ensure better quality in fruits.

4. Conclusion

The paper underlines the importance of food waste reduction, being the major issue affecting natural and economic resources worldwide. This chapter also outlines the interdependence necessary between subjects of the food chain in regard to improving sustainable modes of production and consumption. The research focuses on the study of packaging with the use of smart packaging technology—from incorporating smart coatings into RFID systems that can enhance active packaging in food safety, tracing, and extending shelf life to assist in maintaining food quality and reduction of food spoilage. The conflict can be seen between the preservation techniques and the sensory quality. In this case, it has been stated that though the enrobed mangoes may have an extended shelf life, they have blunt flavors and less appealing colors. This could affect consumer acceptance and marketability as well. The chapter proposes the study of various enrobing materials and the addition of natural flavor enhancers to enhance flavor retention without compromising the shelf stability. This will help in solving the problems of consumer preference for flavor versus nutrition. The findings reveal that fruits, such as mango fruit, have a highly important physical appearance and sensory characteristics since it may all influence characteristics such as consumer preference, which in turn may affect sales and consumer loyalty.

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