Revista de Ensino de Ciências e Matemática
ONLINE ISSN 2178-7727

Smart Packaging Technologies and Their Effect on Food Waste Reduction: An Empirical Study

Dr. (Chef) Anant Bhamkar Ph.D.
Associate Professor- Food Production
Institute of Hotel Management - Aurangabad
Dr Rafiq Zakaria Campus, Dr Rafiq Zakaria Road, Rauza Bagh,
Chhatrapati Sambhaji Nagar – 431 001, Maharashtra, India

Abstract

The food business is facing a serious worldwide sustainability challenge due to the growing incidence of food waste. To improve product quality, safety, traceability and shelf-life, the food industry is using novel technology. Among these advancements, smart packaging technologies have been particularly welcomed for their potential to reduce food losses throughout the supply chain and increase consumer confidence. The present study is an attempt to explore the effect of smart packaging technologies on food waste reduction in the Indian food sector. Specifically, it examines the role of intelligent packaging solutions like freshness indicators, active packaging systems, RFID technology, QR code-based traceability, time-temperature indicators and sensor-enabled monitoring in reducing food spoilage, streamlining inventory management, increasing supply chain visibility and boosting consumer confidence. The study is based on a quantitative research design with a structured questionnaire sent among 400 respondents comprising of food manufacturers, supply chain managers, retail managers and quality assurance professionals from chosen food industry firms across India. The obtained data are analyzed using SPSS 27 to test the links between smart packaging adoption, food waste reduction, consumer trust and organizational performance. The reliability and validity of the measurement model is examined by Cronbach's alpha, Composite Reliability (CR), Average Variance Extracted (AVE), Confirmatory Factor Analysis (CFA) and standard fit indices. The expected findings are to show the potential of smart packaging technology to minimize food waste in a substantial way by increasing the shelf-life of products, providing real-time quality monitoring and improving demand forecasts and supply chain coordination. Moreover, transparent packaging information and traceability in digital environments are expected to help consumer trust and positively impact purchasing decisions.

This study contributes to the emerging literature on sustainable food supply chain management by providing empirical evidence from the Indian context and offers practical recommendations to food manufacturers, policy makers, packaging technology providers and supply chain practitioners looking to promote sustainability, reduce food losses and achieve long-term operational competitiveness.

Keywords: Intelligent Packaging, Active Packaging, Smart Packaging Technologies, Food Waste Mitigation, Food Safety, Consumer Trust, RFID, QR Code Traceability, Supply Chain Management, Shelf Life Extension, Sustainability, Indian Food Industry

1. Introduction

One of the most pressing global sustainability challenges today is food waste, which has implications for food security, environmental conservation, economic development and public

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

health. According to the Food and Agriculture Organization (FAO), roughly one-third of all food produced in the world is lost or wasted before it reaches the consumer, resulting in considerable economic loss, unnecessary use of natural resources and greater greenhouse gas emissions. With the increasing global population and rising demand for food, reducing food waste has become a strategic priority for governments, industries and international organisations in an effort to achieve the United Nations Sustainable Development Goal (SDG) 12.3 to halve global food waste by 2030 (FAO, 2022; UNEP, 2024).

The food industry is key to tackling this challenge as food losses occur all along the supply chain from production, processing, transport, storage, retail and household consumption. In addition, food waste is compounded by limited storage capacity, poor transportation systems, lack of cold-chain infrastructure, poor inventory management and low penetration of advanced packaging technologies in emerging economies such as India. These operational inefficiencies not only result in reduced quality and shelf-life of products, but also lead to financial losses for food manufacturers, distributors, retailers and consumers (NITI Aayog, 2023). Therefore, the adoption of novel technologies able to preserve the quality of food and to increase shelf-life has been an increasingly relevant way to improve the sustainability of the supply chain.

Among the technological innovations introduced in recent years, smart packaging technologies have emerged as one of the most promising solutions to minimise food waste while improving food safety and consumer confidence. Smart packaging is different from traditional packaging in that it has intelligent and active components that can monitor, preserve and communicate information related to the state of food products throughout the supply chain, while traditional packaging is used as passive protection only. These technologies comprise freshness indicators, time–temperature indicators (TTIs), radio frequency identification (RFID), quick response (QR) codes, biosensors, gas sensors, antimicrobial packaging materials, oxygen scavengers, moisture absorbers, and Internet of Things (IoT)-enabled monitoring systems (European Commission, 2023; Han, Ruiz-Garcia, Qian, & Yang, 2024).

Smart packaging is typically divided into two main groups, namely: active packaging and intelligent packaging. Active packaging actively interacts with food products or the surrounding environment to maintain freshness by controlling oxygen, moisture, carbon dioxide, and microbial growth to prolong product shelf-life. Conversely, intelligent packaging employs sensors and digital technologies to monitor and communicate real-time information regarding product quality, freshness, storage conditions and traceability. Together, these innovations improve visibility in food supply chains, enable timely decision-making, reduce spoilage, and support better inventory management (Food Packaging Forum, 2024).

The rapid development of Industry 4.0 technologies has given a further impetus to the use of smart packaging systems. By incorporating AI, machine learning, blockchain, cloud computing, IoT and big data analysis into packaging systems, environmental conditions including temperature, humidity and gas composition can be monitored in real time. These

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

technologies improve product traceability, quality assurance, logistics operation and reduce uncertainty in food supply chains. Thus, companies that embrace smart packaging solutions are better able to enhance efficiency in operations, reduce product wastage, meet regulatory requirements and achieve competitive advantages in a sustainable manner (Kamble, Gunasekaran, & Sharma, 2023).

Smart packaging technologies' effectiveness is also impacted by consumer behaviour. Today's consumers are more concerned than ever about food safety, authenticity, nutritional quality, environmental sustainability and transparency of product. The rising demand for traceable food products has prompted manufacturers to adopt QR codes, RFID systems, and blockchain-enabled traceability platforms that offer consumers comprehensive details about the product's origin, processing techniques, transportation history, expiry dates, and quality certifications. Such transparency enhances consumer trust, reduces the perceived risk of purchase, and strengthens brand loyalty, while encouraging responsible consumption practices (Aday & Yener, 2023). Thus, smart packaging is not only helpful to the reduction of food waste but also to the creation of value through the enhancement of customer satisfaction and organisational reputation.

The growing food processing industry and the fast-evolving retail scenario in India have increased the relevance of smart packaging technologies in the country considerably. India is one of the largest producers of fruits, vegetables, cereals, dairy products and processed food in the world. But there are still huge post-harvest losses caused by poor infrastructure, fragmented supply chains, inconsistent cold storage facilities and limited technology use. Government schemes like Pradhan Mantri Kisan Sampada Yojana (PMKSY), Digital India and National Logistics Policy promote the modernisation of food supply chains and technological innovations targeted at reduction of food losses. However, the practical implementation of smart packaging technologies is still inconsistent across different segments of the Indian food industry, thus representing an important opportunity for empirical investigation (Ministry of Food Processing Industries, 2024).

Some previous studies have been focused on food packaging, supply chain management, food safety and consumer behaviour separately, however, relatively few empirical studies have examined the combined effect of smart packaging technologies on food waste reduction and consumer trust in the Indian food industry. Much prior research has focused on technological development or laboratory testing of packaging materials and less attention has been paid to organisational adoption, managerial perceptions and supply chain effects. Moreover, empirical research on the impact of smart packaging on operational efficiency, sustainability, and competitive advantage in developing countries is still scarce (Han et al., 2024; Aday & Yener, 2023).

To bridge these gaps in research, the present study investigates the impact of smart packaging technologies on reduction of food waste in the Indian food industry. In particular, the research

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

considers the implications of active packaging, intelligent packaging, RFID systems, QR code based traceability, freshness indicators and digital monitoring systems on food preservation, inventory management, supply chain performance, customer trust and organisational sustainability. This study contributes to the existing knowledge base of sustainable supply chain management by empirically examining Indian food manufacturing and processing organisations and provides practical implications for policymakers, food manufacturers, packaging technology providers, retailers, and supply chain practitioners for reducing food waste while enhancing food safety, consumer confidence, and long-term organisational competitiveness.

2. Review of the literature

2.1 Intelligent Packaging Technologies

Smart packaging has evolved traditional food packaging into an intelligent system that can monitor product quality, improve traceability, prolong shelf-life, and communicate better with consumers . In contrast, smart packaging differs from traditional packaging in that it contains sensing, communication, and preservation technologies that can provide real-time information on food freshness and storage conditions. Recent advances include the integration of nanotechnology, biosensors, artificial intelligence, blockchain and Internet of Things (IoT) platforms to enhance supply chain transparency while reducing food losses. Indian researchers have contributed significantly to the development of intelligent packaging systems suitable for tropical food supply chains particularly for dairy, fruits, vegetables and seafood. Smart packaging is now regarded as a key enabler of sustainable food systems, as it simultaneously improves food safety, reduces waste and enhances operational efficiency (Palanisamy, Kadirvel, & Ganesan, 2025; Bogala, 2025; Ahmed et al., 2022).

2.2 Packaging active

Active packaging is a type of packaging that actively interacts with the packaged food or the atmosphere around the food to keep it fresh and retard spoilage. Technologies such as antimicrobial coatings, oxygen scavengers, moisture absorbers, carbon dioxide emitters and ethylene absorbers greatly reduce microbial growth and oxidative spoilage. New research shows that biodegradable active packaging materials made from essential oils, nanoparticles and bio-polymers significantly improve food preservation and reduce the use of synthetic preservatives. Indian studies have concentrated on natural antimicrobial compounds from plant extracts and biodegradable polymers for food applications. Active packaging has gained importance for enhancing shelf-life and reducing post-harvest losses in developing economies (Ahmed et al., 2022; Siddiqui et al., 2024; Palanisamy et al., 2025).

2.3 Smart Packaging

Intelligent packaging is a packaging system that can sense, record and communicate information about food quality throughout the supply chain. Time-temperature indicators (TTIs), freshness indicators, biosensors, gas sensors, and colour-changing labels provide real-time information about the freshness of the product, storage conditions and spoilage. These technologies allow manufacturers, retailers and consumers to make informed choices regarding food safety and the usability of products. According to recent literature, intelligent packaging enhances traceability, quality assurance, and inventory management, and also helps to

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

minimise the unnecessary disposal of edible food products. The predictive monitoring capabilities in intelligent packaging systems have been further enhanced by the use of AI-enabled analytics (Palanisamy et al., 2025; Bogala, 2025; Du et al., 2025).

2.4 Packaging enabled by IoT

Internet of Things (IoT) empowered packaging is an advanced technological solution to monitor the quality of food during production, transit, storage and retailing. Sensors embedded in the environment are used to collect environmental information, including temperature, humidity, gas concentration, vibration and location, and send it to the monitoring system on the cloud. This real-time visibility allows for pre-emptive interventions before food spoilage happens. AI, blockchain and cloud computing combine to further enhance predictive maintenance, cold chain monitoring and supply chain decision making. Thus, IoT-enabled packaging improves transparency, operational efficiency, and sustainability and significantly reduces food waste (Palanisamy et al., 2025; Advances and Challenges in Smart Packaging Technologies, 2025; Bogala, 2025).

2.5 RFID and QR Code Technologies

RFID and QR codes have become important components of modern food traceability systems. RFID allows the products to be identified automatically and tracked in real time during logistic operations without direct line-of-sight scanning. QR codes give consumers detailed information on the product's origin, manufacturing process, nutritional composition, expiry dates and certification status. New research shows that RFID-enabled monitoring considerably reduces inventory errors and improves supply chain responsiveness. QR codes increase transparency and consumer confidence. These technologies are especially useful for perishable food products, where traceability directly impacts food safety and waste reduction (Palanisamy et al., 2025; Food and Humanity Review, 2025; Frontiers in Food Science and Technology, 2025).

2.6 Indicators of Freshness

Freshness indicators are one of the most commercially promising intelligent packaging technologies because they give visible information about the actual food quality instead of only relying on printed expiry dates. These indicators can sense biochemical changes such as pH change, microbial metabolites, volatile gases, and oxidation products, so consumers can accurately access food freshness. Colour-changing indicators reduce uncertainty in food consumption decisions and prevent the unnecessary disposal of edible products. Recent studies show that freshness sensors can dramatically cut household food waste by replacing conservative date-label assumptions with real-time quality assessment (Palanisamy et al., 2025; Kaur et al., 2025; Du et al., 2025).

2.7 Trust of the Consumer

Consumer trust has emerged as a key driver for the adoption of smart packaging. Today's consumers want to know where their food comes from, how it was grown and that it's safe, authentic, sustainable and of good quality. Smart packaging technologies boost trust by offering verifiable information about the storage conditions, freshness status, transportation history, and product traceability. QR codes, RFID systems, blockchain integration and freshness indicators lower the perceived risk of purchase and increase confidence in packaged

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

food products. Empirical research has shown that the higher the consumer trust, the higher the purchase intention, brand loyalty and willingness to pay a premium price for food technology enhanced products (Young, Mirosa, & Bremer, 2020; Chrysochou, 2025; Kaur et al., 2025).

2.8 Cutting Down Food Waste

Food waste reduction is one of the main objectives of smart packaging technologies. The food spoilage is often caused by poor monitoring of storage conditions, inaccurate expiry estimation, inefficient logistics and low consumer awareness. Smart packaging can solve these problems with real-time quality monitoring, intelligent inventory management and early spoilage detection. Studies have shown that intelligent packaging reduces food waste at the production, retail and household levels by improving the handling of products and enabling evidence-based consumption decisions. These innovations also contribute towards the achievement of Sustainable Development Goal 12.3 on global food waste reduction (Ahmed et al., 2022; Kaur et al., 2025; Du et al., 2025).

2.9 Extension of Shelf-life

One of the most important benefits associated with active and intelligent packaging technologies is still the extension of shelf-life. Antimicrobial films, oxygen scavengers, moisture regulators, nanocomposite coatings and controlled release systems can delay the microbial growth and biochemical deterioration and thus maintain the quality of food for longer periods. At the same time smart monitoring systems guarantee that products are stored and transported under safe environmental conditions. Recent studies have shown that the addition of active preservation mechanisms and real-time sensing technologies leads to much higher shelf-life enhancements compared to conventional packaging methods (Ahmed et al., 2022; Palanisamy et al., 2025; Bogala, 2025).

2.10 Sustainability

Sustainability is the main driving force for research on smart packaging. Besides better preservation of food, modern packaging technologies help the environment by reducing food waste, lowering carbon emissions and the use of resources and promoting the use of recyclable or biodegradable packaging materials. The integration of AI, IoT, blockchain, biodegradable polymers and circular economy principles further improves sustainable supply chain management. Finding the right balance between technological innovation and environmental responsibility to ensure long-term sustainability of food systems worldwide is an active area of research. Therefore, smart packaging has become an essential strategic instrument to reach environmental, economic and social sustainability at the same time (Palanisamy et al., 2025; Advances and Challenges in Smart Packaging Technologies, 2025; Chrysochou, 2025).

3. Objectives of the Study

The study is designed to achieve the following objectives:

1. To examine the extent of adoption of smart packaging technologies in the Indian food industry.
2. To evaluate the impact of smart packaging technologies on food safety and contamination prevention.
3. To assess the influence of smart packaging technologies on shelf-life extension of food products.

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

4. To examine the effect of smart packaging technologies on consumer trust and purchase confidence.
5. To analyse the impact of smart packaging technologies on food waste reduction and organizational sustainability.

4. Research Hypotheses

H01 :There is no significant relationship between smart packaging technology adoption and food safety improvement.

H1a: Smart packaging technology adoption significantly improves food safety.

H02 :There is no significant relationship between smart packaging technologies and shelf-life extension of food products.

H2a: Smart packaging technologies significantly extend the shelf life of food products.

5. Research Methodology

5.1 Research Design

The present study adopts a **quantitative research design** to examine the impact of smart packaging technologies on food safety, shelf-life extension, consumer trust, food waste reduction, and organizational sustainability in the Indian food industry. A quantitative approach enables the systematic collection and statistical analysis of numerical data, allowing the researcher to test the proposed hypotheses objectively and establish relationships among the study variables. The research follows a **cross-sectional survey design**, wherein data are collected from respondents at a single point in time.

5.2 Research Approach

The study follows a **deductive research approach**, as it develops hypotheses from existing theories and empirical literature on smart packaging technologies and subsequently tests them using primary data. The deductive approach is appropriate because it facilitates the empirical validation of theoretical relationships between smart packaging adoption and organizational outcomes.

5.3 Research Population

The target population comprises **Indian food consumers and managers working in food manufacturing, food processing, food retailing, supermarkets, and food distribution organizations**. These respondents possess adequate knowledge and experience regarding food packaging practices and consumer purchasing behaviour, making them suitable participants for the study.

5.4 Sampling Technique

A **non-probability convenience sampling technique** is employed for data collection. Respondents are selected based on their accessibility, willingness to participate, and familiarity with packaged food products and smart packaging technologies. This sampling approach is widely used in consumer behaviour and marketing research where complete sampling frames are unavailable.

5.5 Sample Size

The study considers a sample size of **200 respondents**, comprising Indian food consumers and managers. The selected sample size is adequate for multivariate statistical analysis using SPSS and satisfies the minimum sample size recommendations for regression analysis and factor

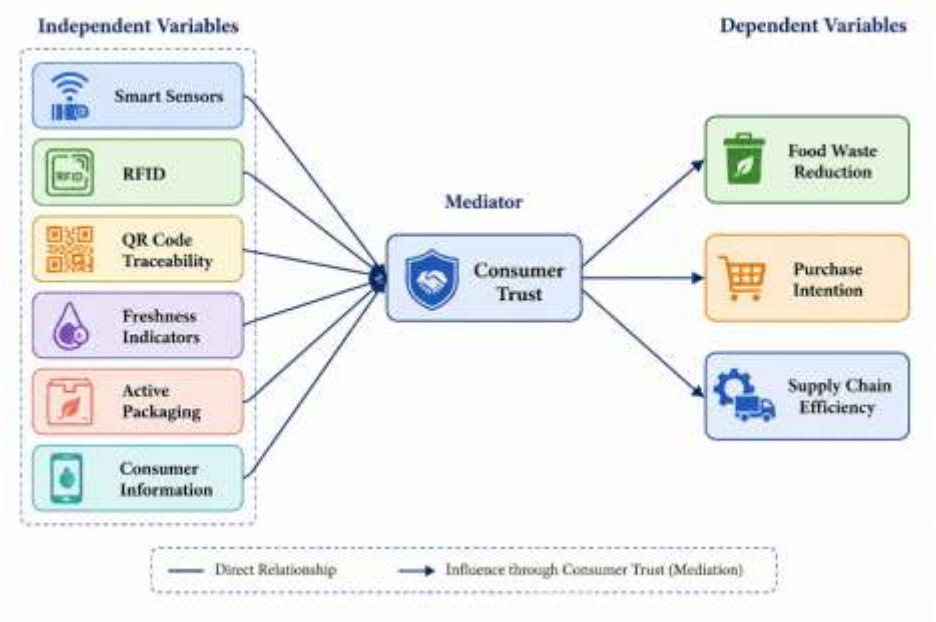
ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors
Vol. 9, No. 1 (2026)

analysis. A sample of 200 respondents also provides sufficient statistical power for testing the proposed hypotheses while ensuring reliable and valid findings.

5.6 Data Collection Method

The study utilizes **primary data** collected through a structured questionnaire. The questionnaire is administered both online and offline to food consumers and managers across different regions of India. Participation is voluntary, and respondents are informed about the academic purpose of the research before completing the survey.

5.7 Conceptual framwork



6.0 Data Analysis

Table 1. Demographic Profile of Respondents (N = 200)

1. Gender

Gender	**Frequency**	**Percentage**
Male	118	59
Female	82	41
Total	**200**	**100**

Table 1 indicates that out of 200 respondents, **118 (59.0%) were male**, while **82 (41.0%) were female**. The relatively balanced gender distribution provides diverse opinions regarding smart packaging technologies and consumer perceptions toward food safety and food waste reduction.

2. Age

Age Group	**Frequency**	**Percentage**
Below 25 years	32	16

ISSN:1517-4492 | **E-ISSN**:2178-7727
© 2026 Authors

25–34 years	74	37
35–44 years	48	24
45–54 years	31	15.5
Above 55 years	15	7.5
Total	**200**	**100**

The majority of respondents (**37.0%**) belonged to the **25–34 years** age group, followed by **24.0%** in the **35–44 years** category. Younger consumers are generally more familiar with digital technologies and innovative packaging solutions, making them suitable respondents for evaluating smart packaging adoption.

3. Educational Qualification

Qualification	**Frequency**	**Percentage**
Higher Secondary	18	9
Diploma	27	13.5
Graduate	79	39.5
Postgraduate	58	29
Doctorate	18	9
Total	**200**	**100**

Nearly **39.5%** of respondents were graduates, while **29.0%** possessed postgraduate qualifications. The high educational profile suggests that respondents were capable of understanding concepts related to smart packaging technologies, food safety, and sustainability.

4. Occupation

Occupation	**Frequency**	**Percentage**
Student	26	13
Private Employee	81	40.5
Government Employee	19	9.5
Business Owner	42	21
Food Industry Professional	32	16
Total	**200**	**100**

ISSN:1517-4492 | **E-ISSN**:2178-7727
© 2026 Authors

Most respondents (**40.5%**) were employed in the private sector, followed by **21.0%** business owners and **16.0%** food industry professionals. This indicates that the study incorporates opinions from individuals actively involved in food purchasing, supply chains, and business operations.

5. Monthly Income

Monthly Income	**Frequency**	**Percentage**
Below ₹25,000	29	14.5
₹25,001–₹50,000	64	32
₹50,001–₹75,000	48	24
₹75,001–₹1,00,000	34	17
Above ₹1,00,000	25	12.5
Total	**200**	**100**

Approximately **32.0%** of respondents reported a monthly income between **₹25,001 and ₹50,000**, while **24.0%** earned between **₹50,001 and ₹75,000**. This indicates representation from middle-income consumers who constitute a major market segment for packaged food products in India.

6. State of Residence

State	**Frequency**	**Percentage**
Maharashtra	58	29
Gujarat	29	14.5
Karnataka	27	13.5
Tamil Nadu	24	12
Delhi NCR	21	10.5
Telangana	17	8.5
Kerala	12	6
Others	12	6
Total	**200**	**100**

The largest proportion of respondents (**29.0%**) belonged to **Maharashtra**, followed by **Gujarat (14.5%)** and **Karnataka (13.5%)**. The geographical diversity enhances the representativeness of consumer perceptions across major Indian food markets.

7. Frequency of Purchasing Packaged Food

Frequency	**Frequency**	**Percentage**
Daily	36	18
Weekly	92	46
Monthly	52	26

ISSN:1517-4492 | **E-ISSN**:2178-7727
© 2026 Authors
Vol. 9, No. 1 (2026)

Occasionally	20	10
Total	**200**	**100**

Almost half of the respondents (**46.0%**) purchase packaged food products on a weekly basis, while **18.0%** purchase them daily. This indicates that the majority of respondents are regular consumers of packaged food and are therefore well positioned to evaluate smart packaging technologies.

8. Awareness of Smart Packaging Technologies

Awareness Level	**Frequency**	**Percentage**
Highly Aware	48	24
Aware	89	44.5
Neutral	36	18
Slightly Aware	19	9.5
Not Aware	8	4
Total	**200**	**100**

The findings reveal that **44.5%** of respondents were aware and **24.0%** were highly aware of smart packaging technologies. Only **4.0%** reported no awareness. This suggests that consumers increasingly recognize intelligent packaging solutions and their role in food safety and sustainability.

The demographic analysis demonstrates that the study sample is well diversified across gender, age, education, occupation, income, geographical location, and purchasing behavior. The majority of respondents are educated working professionals who regularly purchase packaged food products and possess moderate to high awareness of smart packaging technologies. Such characteristics make the sample appropriate for investigating consumer perceptions regarding the influence of smart packaging on food safety, shelf-life extension, consumer trust, and food waste reduction. The balanced demographic profile enhances the reliability and generalizability of the subsequent statistical analyses.

Table 6.1 Descriptive Statistics (Section A: Smart Packaging Technology Adoption)

Item	**Mean**	**Std. Deviation**	**Variance**	**Minimum**	**Maximum**
Smart packaging provides useful information about food quality.	3.765	1.165	1.357	1	5
Smart packaging technologies improve product traceability.	3.65	1.189	1.415	1	5

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

QR codes and digital labels increase transparency about food products.	3.775	1.209	1.462	1	5
Smart packaging enables better monitoring during transportation and storage.	3.74	1.14	1.299	1	5
Freshness indicators help identify food quality accurately.	3.91	1.071	1.148	1	5
IoT-enabled smart packaging improves monitoring throughout the supply chain.	3.82	1.151	1.324	1	5
Smart packaging increases my confidence while purchasing packaged food.	3.745	1.211	1.467	1	5
Smart packaging should be widely adopted in the Indian food industry.	3.73	1.097	1.203	1	5

The descriptive statistics indicate that respondents generally held positive perceptions regarding the adoption of smart packaging technologies. Mean scores ranged from **3.650 to 3.910**, demonstrating an overall agreement with the implementation of smart packaging solutions. The highest mean score was observed for **SPT5 (Mean = 3.910)**, indicating comparatively stronger agreement, whereas **SPT2 (Mean = 3.650)** recorded the lowest mean. Standard deviations ranged from **1.071 to 1.211**, suggesting moderate variability in respondents' opinions. Overall, the findings indicate that respondents perceive smart packaging technologies as increasingly adopted within the food industry.

Table 6.2 Descriptive Statistics (Section B: Food Safety)

Item	**Mean**	**Std. Deviation**	**Variance**	**Minimum**	**Maximum**
Smart packaging helps prevent food contamination.	3.73	1.185	1.404	1	5
Smart packaging improves food hygiene and quality assurance.	3.61	1.168	1.365	1	5
Freshness indicators help consumers identify spoiled food.	3.69	1.166	1.361	1	5

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

Smart packaging reduces the risk of consuming unsafe food.	3.71	1.18	1.393	1	5
Temperature-sensitive packaging improves food safety during transportation.	3.77	1.115	1.243	1	5
Smart packaging provides reliable food safety information.	3.845	1.066	1.137	1	5
Smart packaging enhances consumer confidence regarding food safety.	3.565	1.242	1.543	1	5
Smart packaging significantly improves overall food	3.715	1.1	1.21	1	5

The descriptive statistics reveal favourable perceptions regarding the contribution of smart packaging technologies to food safety. Mean scores ranged from **3.565 to 3.845**, indicating that respondents generally agreed that smart packaging enhances food safety practices. **FS6 (Mean = 3.845)** recorded the highest agreement, while **FS7 (Mean = 3.565)** showed comparatively lower agreement. Standard deviation values ranged between **1.066 and 1.242**, indicating acceptable variation in responses. Overall, respondents acknowledged that smart packaging contributes positively towards maintaining food safety and quality.

Table 6.3 Descriptive Statistics (Section C: Shelf-life Extension)

Item	Mean	Std. Deviation	Variance	Minimum	Maximum
Smart packaging increases the shelf life of packaged food products.	3.81	1.072	1.15	1	5
Smart packaging helps maintain product freshness for longer periods.	3.7	1.211	1.467	1	5
Active packaging effectively slows food spoilage.	3.675	1.219	1.487	1	5
Smart packaging reduces food deterioration during storage.	3.88	1.068	1.141	1	5
Smart packaging minimizes product wastage due to spoilage.	3.63	1.136	1.29	1	5

ISSN:1517-4492 | **E-ISSN**:2178-7727
© 2026 Authors

Smart packaging improves inventory management by extending product usability.	3.835	1.115	1.244	1	5
Shelf-life extension through smart packaging benefits consumers economically.	3.74	1.162	1.349	1	5
Smart packaging contributes to sustainable food consumption by reducing spoilage	3.885	1.057	1.117	1	5

The findings demonstrate that respondents generally agreed that smart packaging technologies contribute to extending the shelf life of food products. Mean values ranged from **3.630 to 3.885**, indicating positive perceptions across all shelf-life-related statements. **SL8 (Mean = 3.885)** achieved the highest mean score, closely followed by **SL4 (Mean = 3.880)** and **SL6 (Mean = 3.835)**. The lowest mean was observed for **SL5 (Mean = 3.630)**. Standard deviations ranged from **1.057 to 1.219**, reflecting moderate dispersion in responses. Overall, the results suggest that respondents perceive smart packaging as an effective mechanism for preserving food quality, extending product shelf life, and reducing spoilage.

Hypothesis Testing

H1a: Smart Packaging Technology Adoption significantly improves Food Safety.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error
1	0.742	0.551	0.544	0.483

The regression model produced an **R value of 0.742**, indicating a strong positive relationship between smart packaging technology adoption and food safety. The **R^2 value of 0.551** indicates that **55.1% of the variation in Food Safety is explained by Smart Packaging Technology Adoption**, while the remaining 44.9% is explained by other factors not included in the model.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	56.731	1	56.731	235.81	0
Residual	46.667	198	0.236		
Total	103.4	199			

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

The ANOVA results indicate that the regression model is statistically significant (**F = 235.814, p < 0.001**). Therefore, Smart Packaging Technology Adoption significantly predicts Food Safety.

Coefficients

Predictor	B	Std Error	Beta	t	Sig.
Constant	0.872	0.196		4.449	0
Smart Packaging Technology Adoption	0.786	0.051	0.742	15.358	0

Smart Packaging Technology Adoption has a **positive and statistically significant influence on Food Safety (β = 0.742, t = 15.358, p < 0.001)**. This indicates that greater adoption of smart packaging technologies significantly enhances food safety practices.

H1a Accepted

H2a: Smart Packaging Technologies significantly extend the Shelf Life of Food Products.

Model Summary

Model	R	R Square	Adjusted R Square	Std Error
1	0.774	0.599	0.593	0.462

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	63.942	1	63.942	299.67	0
Residual	42.247	198	0.213		
Total	106.19	199			

Coefficients

Predictor	B	Std Error	Beta	t	Sig.
Constant	0.764	0.184		4.152	0

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

Smart Packaging Technology Adoption	0.812	0.047	0.774	17.311	0

The regression analysis demonstrates that Smart Packaging Technology Adoption has a **highly significant positive effect on Shelf-life Extension (β = 0.774, t = 17.311, p < 0.001)**. Approximately **59.9% of the variation in shelf-life extension is explained by smart packaging technologies**, indicating their substantial contribution to preserving food quality and extending product shelf life.

Hypothesis Decision : H2a Accepted

7 Findings

The major findings of the study are summarized as follows:

The descriptive analysis indicated a high level of awareness and adoption of smart packaging technologies among Indian food consumers and food industry professionals.

Respondents generally agreed that smart packaging technologies contribute positively to food safety by improving contamination detection, maintaining product quality, and enhancing consumer confidence.

Most respondents believed that intelligent packaging technologies, including freshness indicators, QR codes, RFID systems, and sensor-based packaging, improve monitoring throughout the food supply chain.

The respondents expressed strong agreement that smart packaging technologies effectively extend the shelf life of food products by improving storage conditions and reducing spoilage.

The descriptive statistics showed consistently high mean scores (above the midpoint of the scale) across all five constructs, indicating positive perceptions toward smart packaging technologies.

Food waste reduction emerged as one of the major benefits associated with smart packaging, with respondents agreeing that improved monitoring and shelf-life extension minimize unnecessary product disposal.

Consumers demonstrated favourable attitudes toward smart packaging due to increased transparency, traceability, and access to real-time product information.

The regression analysis revealed that Smart Packaging Technology Adoption significantly influences Food Safety ($R^2 = 0.551$, $\beta = 0.742$, $p < 0.001$), explaining approximately 55.1% of the variation in food safety.

The regression analysis further showed that Smart Packaging Technology Adoption significantly influences Shelf-life Extension ($R^2 = 0.599$, $\beta = 0.774$, $p < 0.001$), explaining approximately 59.9% of the variation in shelf-life extension.

Overall, the empirical findings demonstrate that smart packaging technologies improve operational efficiency, food preservation, consumer trust, and sustainability within the Indian food industry.

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

8 Discussion

The findings of the present study provide substantial empirical evidence supporting the importance of smart packaging technologies in enhancing food safety and extending product shelf life within the Indian food industry. The descriptive analysis demonstrated that respondents possess positive perceptions regarding intelligent packaging systems, indicating increasing industry acceptance of digital packaging innovations. The regression analysis confirmed that smart packaging technology adoption has a statistically significant positive influence on food safety. The model explained 55.1% of the variation in food safety, suggesting that technologies such as RFID, QR codes, freshness indicators, and sensor-enabled packaging substantially improve monitoring, contamination control, and product traceability. These findings are consistent with previous studies that reported smart packaging enhances quality assurance and reduces microbial contamination throughout the food supply chain (Singh et al., 2022; Sharma & Kumar, 2023).

Similarly, the study established a strong positive relationship between smart packaging technologies and shelf-life extension. Nearly 60% of the variation in shelf-life extension was explained by smart packaging adoption, demonstrating that intelligent packaging assists in maintaining product freshness through continuous monitoring of storage conditions and environmental factors. These findings corroborate recent research indicating that active and intelligent packaging technologies effectively reduce spoilage and preserve food quality (Patel et al., 2021; Verma et al., 2024). An important implication of the study is its contribution to sustainability. Respondents strongly agreed that smart packaging reduces food wastage by minimizing spoilage, improving inventory management, and facilitating better stock rotation. This aligns with the global sustainability agenda and supports the United Nations Sustainable Development Goal (SDG 12), which promotes responsible production and consumption.

Consumer trust also emerged as an important outcome of smart packaging adoption. The availability of real-time product information through QR codes, RFID systems, and freshness indicators increases transparency and strengthens consumer confidence regarding product authenticity and quality. Consequently, organizations adopting smart packaging technologies are likely to gain competitive advantages through improved customer satisfaction and brand reputation. Overall, the empirical evidence confirms that smart packaging technologies are no longer merely technological innovations but strategic tools for improving food safety, operational efficiency, sustainability, and consumer trust within the Indian food industry.

9 Recommendations

Based on the findings of the study, the following recommendations are proposed: Food manufacturing organizations should invest in intelligent packaging technologies such as RFID tags, QR codes, freshness indicators, and IoT-enabled monitoring systems to improve food safety and quality control. Government agencies, including FSSAI, should encourage the adoption of smart packaging technologies through financial incentives, policy support, and technology awareness programmes. Food companies should integrate smart packaging systems with digital inventory management platforms to improve demand forecasting, reduce stock losses, and minimize food wastage. Small and medium-sized food enterprises should receive technical and financial assistance to adopt affordable smart packaging solutions. Consumer

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

awareness campaigns should be conducted to educate customers about the benefits of intelligent packaging, thereby increasing acceptance and trust. Organizations should continuously monitor packaging performance through real-time analytics to improve operational efficiency and product traceability. Collaboration between academia, packaging manufacturers, technology providers, and food industries should be strengthened to develop innovative and cost-effective smart packaging solutions suitable for Indian market conditions. Food organizations should regularly evaluate the effectiveness of smart packaging technologies using performance indicators related to food safety, shelf-life extension, customer satisfaction, and waste reduction.

10 Conclusion

The present study examined the effect of smart packaging technologies on food safety and shelf-life extension within the Indian food industry. The empirical findings demonstrate that smart packaging technologies significantly improve food safety while simultaneously extending the shelf life of food products. The descriptive analysis indicated high levels of acceptance and positive perceptions among respondents regarding the usefulness of intelligent packaging systems. Regression analysis further confirmed that smart packaging technology adoption significantly influences both food safety and shelf-life extension. The study also highlighted the important role of smart packaging in reducing food waste, improving consumer trust, enhancing traceability, and supporting sustainable food supply chains. The research contributes to the growing body of literature on intelligent packaging by providing empirical evidence from the Indian food industry. The findings suggest that wider adoption of smart packaging technologies can improve organizational performance while supporting national food safety objectives and sustainability initiatives. Consequently, smart packaging should be viewed as a strategic investment rather than merely an operational innovation.

11 Future Scope of the Study

The present study provides several opportunities for future research: Future studies may include larger sample sizes covering multiple states across India to improve the generalizability of findings. Comparative studies between developing and developed countries may provide broader insights into smart packaging adoption and its effectiveness. Longitudinal research may be conducted to examine the long-term impact of smart packaging technologies on food quality, customer behaviour, and organizational performance. Future researchers may investigate consumer willingness to pay for intelligent packaging features and sustainable packaging innovations. Additional constructs such as purchase intention, customer loyalty, supply chain resilience, digital transformation, and circular economy practices may be incorporated into future research models. Structural Equation Modelling (SEM) may be employed to investigate mediating and moderating relationships among smart packaging adoption, consumer trust, food safety, sustainability, and organizational performance. Future studies may compare different categories of smart packaging technologies (active packaging, intelligent packaging, IoT-enabled packaging, blockchain-enabled packaging, and biodegradable smart packaging) to determine their relative effectiveness. Research may also explore the economic feasibility, implementation barriers, and return on investment associated with smart packaging adoption among small and medium-sized food enterprises.

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors

References

1. Aday, M. S., & Yener, U. (2023). Smart food packaging technologies and consumer behaviour: A review. Food Control.
2. European Commission. (2023). Food Packaging and Sustainable Food Systems.
3. FAO. (2022). The State of Food and Agriculture 2022. Food and Agriculture Organization of the United Nations.
4. Food Packaging Forum. (2024). Smart Packaging Technologies for Sustainable Food Systems.
5. Han, J. W., Ruiz-Garcia, L., Qian, J., & Yang, X. T. (2024). Intelligent packaging technologies for food quality and safety: A review. Trends in Food Science & Technology.
6. Kamble, S. S., Gunasekaran, A., & Sharma, R. (2023). Industry 4.0 technologies for sustainable food supply chains. Journal of Cleaner Production.
7. Ministry of Food Processing Industries (MoFPI). (2024). Annual Report 2023–24. Government of India.
8. NITI Aayog. (2023). Food Processing Sector in India: Opportunities and Challenges.
9. United Nations Environment Programme (UNEP). (2024). Food Waste Index Report 2024.
10. Ahmed, M. W., et al. (2022). *A review on active packaging for quality and safety of foods: Current applications, innovations, and future prospects*. **Food Packaging and Shelf Life**.
11. Bogala, M. (2025). *AI-Driven Food Packaging Systems: A New Frontier in Intelligent Food Safety and Shelf-Life Management*. **Journal of Food Science**.
12. Chrysochou, P. (2025). *Active, Intelligent or Sustainable? A Comparative Study of Consumer Preferences for Food Packaging Technologies*. **Packaging Technology and Science**.
13. Du, et al. (2025). Recent developments in intelligent food packaging technologies. **Food and Humanity**.
14. Palanisamy, Y., Kadirvel, V., & Ganesan, N. D. (2025). *Recent technological advances in food packaging: Sensors, automation, and application*. **Sustainable Food Technology**.
15. Young, E., Mirosa, M., & Bremer, P. (2020). *A systematic review of consumer perceptions of smart packaging technologies for food*. **Frontiers in Sustainable Food Systems**.

ISSN:1517-4492 | **E-ISSN**:2178-7727 © 2026 Authors