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Article

Evaluation of the impact of intelligent logistics systems based on biosensors on food preservation effect

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Abstract: Intelligent logistics systems have been advanced enough to connect with biosensors to act as an innovation in the food industry especially in food preservation. In this paper, the author assesses the effectiveness of the utilization of intelligent logistics systems particularly biosensors on food preservation efficiency considering the capability of the technologies to provide real-time environmental information including temperature, humidity, and contamination scenarios. They refer here to biosensors embedded in packaging or storage units so that they can monitor the relevant data and make adjustments when necessary all over the supply chain. This kind of data can be used to allow intelligent logistics systems to make logistics decisions on how to best preserve perishable goods minimize cases of spoilage and increase the shelf life of such products. Using a multiple case study methodology, in this research the authors analyse the experiences of food supply chains that have implemented biosensor logistics. The study focuses on the effects of reducing food waste in terms of qualitative measurement of food preservation, along with increased benefits for food producers, distributors and sellers. Additionally, the paper discusses how biosecurity technology solutions are restricted technologically, financially, and in terms of their application in biosensors for various sections of the food chain. This research shows that the integration of the biosensors into the logistics system creates a positive impact on the challenge of food preservation especially in temperature-sensitive and perishable products including fruits and vegetables, dairy products and seafood. However, global implementation has some challenges which include; initial costs associated with implementation and enormous infrastructural support. The recommendations of this specific paper concern the proposed deployment strategy of biosensors in intelligent logistics.

Keywords: intelligent logistics; biosensors; food preservation; supply chain management; food safety; perishable goods; food waste reduction; environmental conditions; temperature control; humidity control; contamination detection

1. Introduction

Different segments of the food supply chain are challenged by such global trends as quality, safety, and sustainability. Approximately one-third of all food that is processed is wasted, hence food preservation has emerged as an important problem for manufacturers and customers alike. Spoilage has lots of implications since taking substandard products, which result from spoilage impacts negatively on people's health. Conventional systems of logistics do not adequately account for current external conditions, which are vital towards the preservation of perishables [1]. In the last few years, the progress in technology has brought about the application of intelligent logistics systems which apply the Internet of Things, artificial intelligence and analysis of big data. Such systems can provide dynamic control of the different stages of a supply chain and the right conditions for food storage. An up-and-coming technology in this area is biosensors technology, devices with the potential to measure certain environmental prerequisites like temperature, humidity and microbial presence in real-time. Hence, these sensors can be placed on packaging or storing facilities to help companies have instant information on the state of their products to make remedies early reducing wastage.

The incorporation of biosensors into the logistics networks presents an innovative concept of food preservation. It provides for constant checking, noting and evaluating which helps to make decisions on how to store the products, how to transport them, and stock control. For example, if the biosensor is used to measure the temperature and notice that the temperature is above or below the suitable range of the perishable item, an alert can cause quick corrective measures like a change of the temperature, or a change of the shipment's route [2]. This capability also improves both food safety and quality, while also lowering waste levels since items remain fresh for longer periods. However, as it is clear from the evaluating factors illustrated above, the deployment of intelligent logistics systems with biosensors remains unestablished at its basic level. Challenges like high implementation costs, the challenge of accommodating new technologies within the paradigm of the current system, and basic staff training act as non-negotiable hurdles. Furthermore, while several players in the industry have adopted these technologies, there are no integrated analyses of the results of biosensor-based logistics on food preservation.

This paper seeks to meet this gap by presenting an assessment of the effects of intelligent logistics systems that use biosensors on food preservation. To this end, the research will explore the various ways through which these technologies enhance preservation efficacy, lower spoilt food proportion, and generate additional value for all the stakeholders in the Food Industry Value Chain. The research is designed as a case study analysis and statistical data analysis that would provide useful insights into the prospects of using biosensors to manage the flow of produce and, thereby, transform fresh food conservation systems. Finally, it aims to explain why such innovations are important in tackling the major issues of the food industry of the present day.

1.1. Problem statement

As can be seen from the Food Supply Chain Map, the food supply chain includes many challenges which have considerable obstacles to food deterioration and waste. Close and constant monitoring of the old supply chain infrastructure is needed, resulting in poor preservation requirements that affect the quality and standard of the consignment. Traditional techniques used for handling perishable goods are thus more or less crisis-oriented, which makes their spoilage and the consequent shrinkage of stock higher in comparison to the use of modern technologies [3]. Technological enhancements of the food supply chain have not been met with the implementation of biosensors utilising intelligent logistics systems due to the perceived cost of implementation, integration issues and general misunderstanding of its benefits. This research therefore tries to fill this gap by assessing the effectiveness of biosensor-based intelligent logistics on food preservation, in a bid to find data to back increased adoption of the technology by the food industry.

1.2. Objectives

1) To estimate the impact of biosensors on the effectiveness of preservation in logistics systems through having access to the real-time controls of the most significant parameters like temperature and humidity.
2) To measure the degree to which biosensor-wear logistics systems offer solutions to minimizing food losses and waste in the supply chain.
3) To compare the economic impacts of the adoption of intelligent logistics systems with the use of biosensor technology to the benefits of decreased waste and enhanced shelf life of perishable products.
4) To investigate the difficulties companies, encounter while adopting such technologies and how they deal with costs, training requirements, and compatibility with organizational systems.
5) In the Proposition for the stakeholders involved in the food supply chain to provide specific advice concerning the use of biosensors in improved food preservation strategies.

1.3. Significance of the study

The novelty of this particular work is its ability to advance the existing literature on intelligent logistics systems and biosensors used on food products. Using an assessment of the effects of these innovations in food preservation, this study offers useful information concerning returns and the feasibility of applying intelligent logistics systems to food producers, distributors and retailers. Understanding this is vital when it comes to determining key areas in which an organization needs to invest to obtain the best technology for organizational improvement and subsequent quality of its products. In addition, it addresses one of the most pressing issues that nowadays the global food supply chain focuses on the problem of food waste, where biosensors can play an important part [4]. In this regard, the research helps save the environment together by boosting business sustainability not through making extra sales but by identifying how to reduce spoilage in fruits and vegetables. Also, they can help policymakers who are concerned with a drive towards the innovation of technology in the food industry and may help cause a new drive towards the revelation of more sustainable means of preserving food. Consequently, this research forms the basis of subsequent research on technology in relation to food preservation in supply chain management with a view of propelling improvement in the practices. Recognizing such main issues in the food industry the study is aimed at paving the way for the utilization and implementation of intelligent logistics systems and biosensor technology to improve food safety and quality leading to the consumers' gain and the society as a whole.

2. Literature review

2.1. Intelligent logistics systems

Smart logistics concepts are new-era supply chain management techniques which utilize the latest tools to increase the functionality, transparency, and flexibility of the logistics, and the interaction between machines through the Internet of Things, artificial intelligence, big data analysis, and evaluation of machine learning scenarios so as to form a supply chain network that provides real-time responsiveness to circumstances.

2.1.1. Key components of intelligent logistics systems

Internet of Things (IoT): Due to advances in technology, wireless sensors and RFID tags can be used to monitor shipments in the supply chain process. They gather information on the luminosity, the temperature, the humidity and other factors which influence the quality of the products or make them unsafe [5].

Artificial Intelligence (AI) and Machine Learning: Big data is accumulated through the Internet of Things devices, and AI algorithms are used for processing the obtained data to detect certain patterns and forecast possible problems. Machine learning models are thus useful in logistics to forecast demand, identify the right delivery routes, and even work to manage inventories.

Big Data Analytics: The data collected through connected IoT devices are big in quantity and are analyzed using big data tools. They assist in pulling valuable intelligence out of the data for decision-making purposes and supply chain transparency among many firms.

Cloud Computing: The intelligent logistics systems produce accumulated data, which can be stored and analyzed on cloud solutions. They also give simple and direct access to data and analytics for oneself and other supply chain partners [6].

Blockchain Technology: Through blockchain, more transparency and traceability are made possible and actually embodied in the supply chain to determine the security of the transactions. This is particularly important so that foods are free from contaminants in order to meet the standards set by the regulators.

All the key Components of Intelligent Logistics Systems are shown in **Figure 1**.

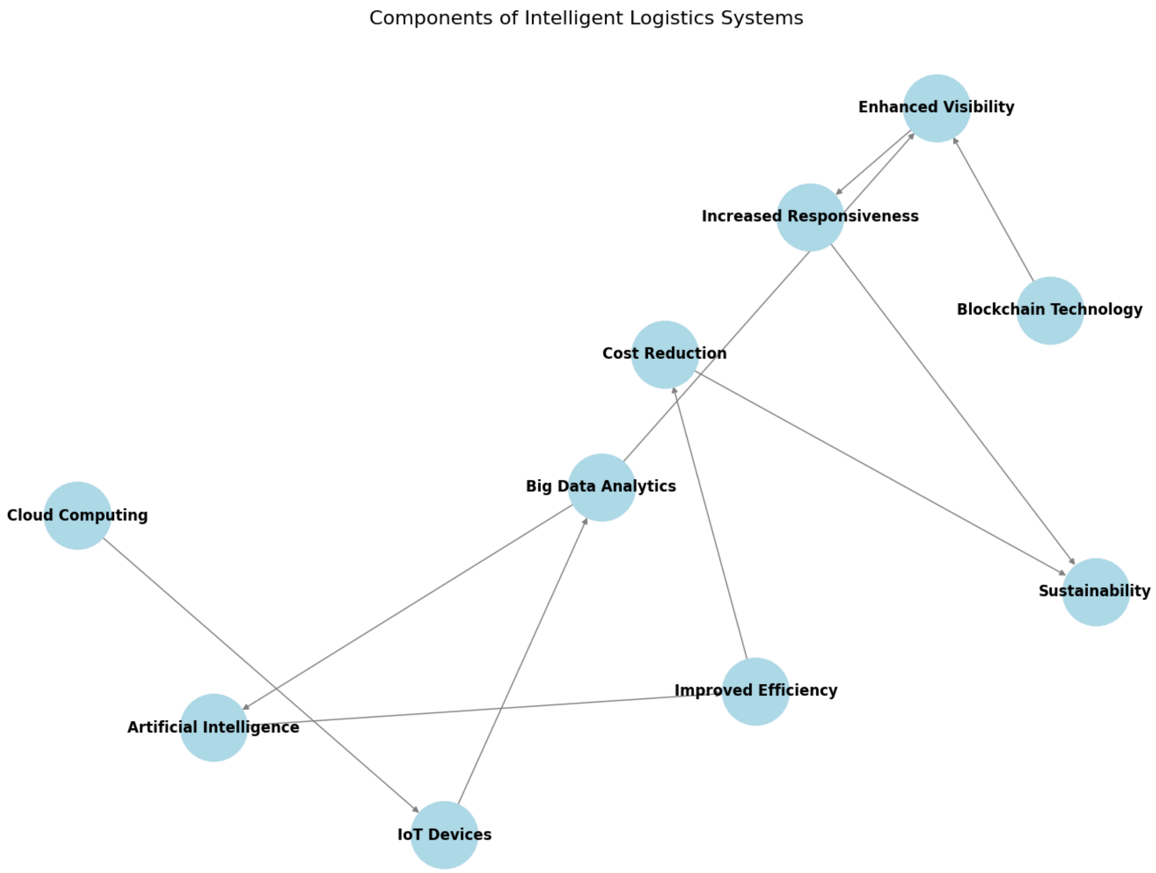

Figure 1. Components of intelligent logistics systems (Created by author).

2.1.2. Benefits of intelligent logistics systems

Improved Efficiency: Intelligent logistics systems in essence enhance the efficiency of the processes by performing similar tasks that would otherwise necessitate the input of the personnel while at the same time discharging common and repetitive tasks.

Enhanced Visibility: Tracking goods enables the various stakeholders to assess the status of the shipments and stocks in order to enhance their interaction process in the supply chain, on a real-time basis.

Cost Reduction: Specifically, the creation of intelligent logistics through the correct path planning, reduction of loss and damage as well as more efficient supply chain inventory can greatly chisel the cost of companies.

Increased Responsiveness: A company can effectively keep track of conditions in any given environment and respond to disruptions depending on delays and changes in demand.

Sustainability: Technologies and information systems play an important role in the optimization of supply chain flows and can both minimize waste and contribute to improved sustainability of the supply of perishable goods.

2.2. Biosensor technology

Biosensor as a technology has proved strategic in addressing food preservation that enables the assessment of the quality and wholesomeness of foods throughout the distribution system. A biosensor is generally comprised of a biologically active component, normally an enzyme, an antibody or a microbial cell, coupled with a physical transducer that translates the biological response into an accessible signal [7]. This capability allows for the identification of condiments such as temperature, water activity, pH, or contaminants of pathogenic or spoilage organisms.

2.2.1. Types of biosensors in food preservation

Temperature Sensors: These biosensors maintain a check on the changing temperature that affects food safety and quality. For instance, the transportation of perishables such as vaccines has a condition attached to it known as cold chain logistics. Any changes can result in spoilage and therefore having temperature sensors will mean timely detection of a change.

Humidity Sensors: These biosensors are used for monitoring moisture content in the environment. Increased humidity stimulates microbial action and foods which can spoil rapidly are stored grain and bakery products. The trend indicates that it is possible for stakeholders to take appropriate action by controlling the level of humidity to enhance the right storage conditions.

pH Sensors: These parameters are very important as far as food quality and safety are concerned particularly the pH. Shifts in the pH levels may indicate that food has gone bad or has been contaminated in some way. Devices for evaluating the level of acidity and alkalin are pH indicators.

Microbial Sensors: These biosensors identify particular pathogenic or spoilage microorganisms to enable understanding of food safety. Knowing when a food product is contaminated by microbes helps the company control the dangers that come with the products before they harm many customers. **Table 1** shows Types of Biosensors in Food Preservation along with parameters monitored and their applications.

Table 1. Types of biosensors in food preservation.

Type of Biosensor	Parameter Monitored	Application
Temperature Sensor	Temperature fluctuations	Cold chain monitoring
Humidity Sensor	Moisture levels	Storage condition control
pH Sensor	pH level variations	Quality assessment
Microbial Sensor	Pathogen detection	Safety assurance

2.2.2. Mechanisms of action

Electrochemical Transduction: This method quantifies the electrical signal produced by a biochemical reaction. The electrochemical biosensors are selective and they can be used for detecting small concentrations of analytic.

Optical Transduction: Label-free biosensors are based on alterations in the light characteristics, i.e., absorbance, fluorescence or reflection provoked by the recognition element-analyte affinity. It can give a fast and highly sensitive detection of the target material.

Mass-sensitive Transduction: These biosensors quantify variations in mass due to the interaction of the target analytes with the recognition element. This method is used in cases where high specificity of the given application as a whole is needed [8].

2.2.3. Advantages of biosensors in food preservation

Biosensors involve several huge benefits in food conservation, the safety as well as the quality of food in the chain of distribution. The first advantage is the ability to constantly control important indicators including temperature, humidity, and microbial activity. This capability facilitates the timely response of the stakeholders in case of any variation hence ensuring the minimization of spoilage and thereby increasing the shelf life of the perishable products. Also, biosensor means enhanced accuracy compared to simple monitoring and are less likely to give either a false positive or a false negative result. This reliability guarantees that food and products that are in circulation are safe and of the right quality. Economical is another benefit since the production of fewer defects, less wastage and better product quality in the long run normally takes precedence over the initial outlay. In addition, a high number of biosensors are compact and simple to operate which enables easy incorporation into logistics networks with minimal training. The specificity of biosensors also enables the identification of specific pathogens and spoilage microorganisms that cause harm to the consumers which enables early corrective action to be instituted.

2.2.4. Limitations of biosensor technology

There are a few limitations that have been presented that hamper the efficient and wide use of biosensors in food preservation: Biosensors are prone to effects such as the effects of light, temperature and humidity due to their inherent biological nature which makes an important consideration. Furthermore, the use of many biosensors requires frequent calibration and maintenance to guarantee high performance, which increases operational expenses and requires employee knowledge [9]. This need for maintenance can be problematic for small businesses that do not have the funds to manage maintain and/or upgrade the technology. Also, the biological components incorporated in biosensors have a limited lifespan and, thus, deteriorate constantly. This indeed requires replacement from time to time hence increasing the overall cost of implementation. Yet another potential shortcoming is the signal interference by matrix-interfering substances that cause positive/negative interference in the result. In addition, the use of biosensors is not very scalable since the efficacy of some of the sensors could reduce drastically when the technology is scaled up to production zones or food variety.

Figure 2 shows the Effectiveness of Biosensors in Food Preservation. Food preservation regimes have been greatly aided by biosensors where important parameters are constantly measured in real time the technology offering a strong backbone to processes. As the smart effective incorporation of diverse biosensors into logistics systems, the application of such systems has the potential to enhance food safety as well as quality management to reduce wastage and enhance stakeholders' economic returns in the food chain. It is pertinent that the food industry should recognize and comprehend the advantages and disadvantages of employing biosensors to force them to enhance their utilization in the preservation of food.

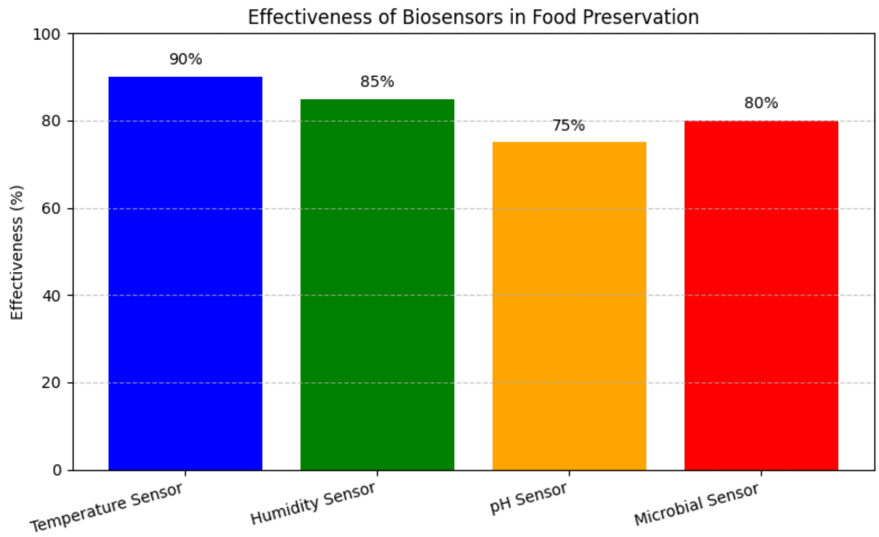

Figure 2. Effectiveness of biosensors in food preservation (Created by author).

2.3. Impact on food preservation

Logistics intelligent technologies and biosensors' use in this context have illustrated a revolution in food preservation. All these improvements not only help to produce better quality and safer foods but also fit well in the general goal of minimizing rates of food spoilage and waste, at the supply systems level. This section deals with how exactly these technologies impact food preservation by use of real-time monitoring, ways of intervention and economic returns [10].

2.3.1. Real-time monitoring

In general, intelligent logistics systems' capability to monitor in real-time is one of their main features. Current innovations in bio-sensing technology have enabled packaging or storage facilities within companies to monitor fundamental environmental factors such as temperature, humidity, and pH levels within the storage environment constantly. For example, it showed that the adoption of temperature-sensing biosensors in cold chain logistics led to quite a high reduction in spoilage rate, with the perishable goods being maintained at the appropriate temperature. This continuous monitoring ensures that stakeholders receive timely notifications any parameter goes off standard ranges for the right corrective actions to be taken [11].

The above visualization (**Figure 3**) shows a clear nexus between real-time monitoring and minimization of food spoilage. The chart also shows the percentage of spoilage decrease implemented by means of biosensors in relation to the usual control.

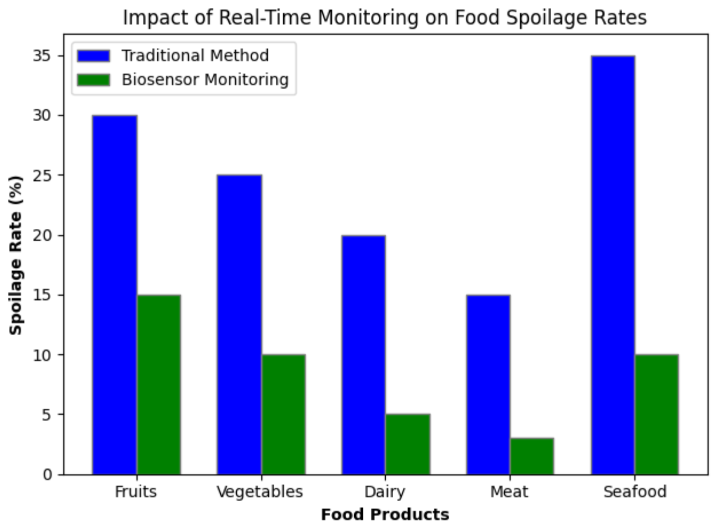

Figure 3. Impact of real-time monitoring on food spoilage rates created by author.

2.3.2. Proactive interventions

The ability to make anticipative interferences is also one of the components of intelligent logistics systems. In the event that biosensors identify a condition such as high temperature in refrigerated storage the facility's management is immediately notified. This makes it possible for immediate intervention measures to be made in areas for instance, modifying temperature regulators, reorganizing the transit of parcels, or inspecting particular commodities with concern [12]. Measures taken early enough are very effective in reducing the degree of spoilage and guaranteeing food quality for consumption.

2.3.3. Economic benefits

Such a type of biosensor application in the sector of logistics is linked with certain economic consequences. Lower spoilage rates have a straight and potential impact on the firm's bottom line. Appreciating the shelf lives of food products leads to increased business returns and general product improvement since consumers are likely to be more loyal. In addition, following inventory management contributes to efficient levels of stock; by using data analytics a business can avoid unnecessary extra costs of unnecessary inventory and waste. According to quantitative research carried out by Zhang et al. [13], organizations implementing biosensor-based logistics systems recorded a reduction in their cost of operations regarding spoiled and wasted products by twenty-five per cent. These economic benefits contribute not only to the growing profitability of intelligent logistics systems but also to the expansion of these systems used in food-related companies and the constant development of improved methods of food preservation.

Smart logistics systems and biosensors implementation are more critical as they cause changes in food conservation. By using real-time monitoring, timely actions, and substantial economic gains, these technologies help to create safer and higher quality food products at the same time minimizing waste. This paper has demonstrated that as the food industry advances, so must the progress of these innovative technologies that will help meet the hurdles facing spoilage and the overall sustainability of the food supply chain complexities.

2.4. Challenges and barriers to adoption

2.4.1. High initial implementation costs

However, the major limitation of adopting an intelligent logistics system is the enhanced first-time implementation cost of the system. This comprises costs like; the cost of biosensor devices, the cost of incorporating biosensors into existing logistics systems and the costs of constructing the logistics systems that are required for constant monitoring and analyzing the collected data in real time. In many SMEs, these costs are very high making many organizations very reluctant to adopt such technologies. Moreover, costs relating to the continual upkeep and calibration of biosensors are also accreted to the cost line.

2.4.2. Complexity of integration

Those who have tried to introduce new technologies in an existing pattern of supply chain management may understand this hurdle easily. Most logistics processes are performed through systems that could be practically incompatible with biosensing biosensors technology. As a rule, the process of integrating these systems implies the acquisition of certain knowledge and skills, which can be unobtainable [14]. Also, there is always the issue of network interconnectivity between the various items, the different platforms, and the stakeholders. These can lead to longer implementation periods and greater levels of dysfunction in operations, which can discourage firms from exploring these developments.

2.4.3. Lack of understanding and awareness

The problem towards enhancing the EOS（Embedded Operating System） of intelligent logistics systems and biosensor technology is the limited awareness of these systems and their features among industry stakeholders. Innovations in refrigeration technology, use of food-friendly packaging material, and monitoring and control methodologies may not be clearly understood by many organizations on how these innovations can actually help enhance the process of preservation and storage, embrace high operational efficiency, and hence, bring about low costs. This lack of awareness can result in resistance to change, as people will be reluctant to invest resources in a technology which they are unaware of the value.

2.4.4. Need for employee training

The measures for the acquisition of intelligent logistics systems and biosensors entail enormous training of the employees who are to ensure the running of these technologies. Such systems raise many issues in training that most organizations fail to implement efficient training that will enable the human resource to use the systems effectively [15]. Resistance to change among staff members together with concerns of job loss resulting from the use of automation in performing some tasks makes training even more challenging.

2.4.5. Data security and privacy concerns

That is, there is a potential danger that depends on the IoT facility data gathering, and data security and privacy. Vendors, transporters, processors, manufacturers, distributors, and consumers need to guarantee that privacy and data breaches are prevented. A common aspect of biosensors is the ability to transfer data over networks which are relatively susceptible to hacking. System security means keeping information secure requires spending in that field making the overall cost of implementing the solution higher.

2.4.6. Regulatory compliance

The food industry has very much legal and regulatory requirements, especially with regard to food safety and quality. These regulations have to be at par with the adopted intelligent logistics systems that differ depending on geographical locations. Operating in the challenging regulatory environment may be difficult and firms may experience some challenges in adhering to the safety standards in the application of the advanced technologies. The bar graph shown in **Figure 4** visualizes the challenges and barriers to Adoption of adoption logistics systems.

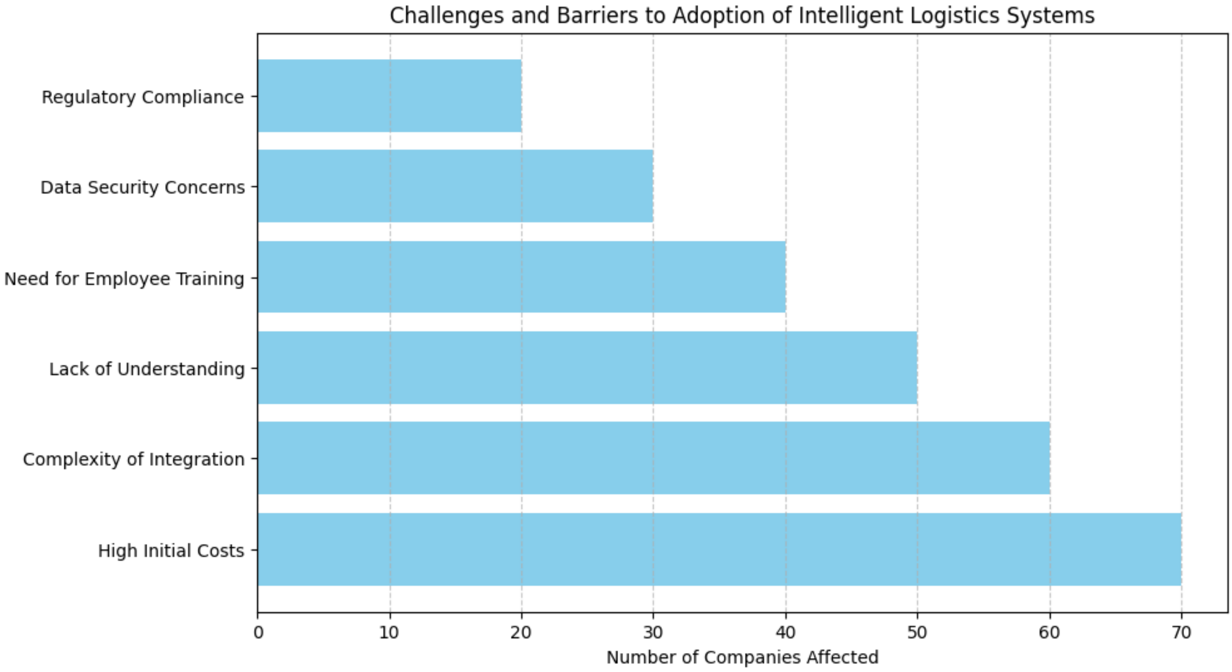

Figure 4. Challenges and barriers to adoption (Created by author).

2.5. Gaps in the literature

Although the significance of intelligent logistics systems and biosensor technology for controlling food spoilage has been underlined by the increasing amount of research, some research gaps can be identified. First of all, there exists a high demand for extensive research on the effectiveness of intelligent logistics and its constituents, including IoT and bio-recognition devices, although separate analysis of the effectiveness of these components has already been made. Much of this research seems to concentrate on individual aspects without paying attention to the general interaction of these technologies with food preservation. It is visually represented in **Figure 5**.

Secondly, most of the prior works only focus on qualitative research methods like case studies or interviewing key informants may be used to make conclusions. However, these qualitative findings are helpful in understanding the nature of the problem but do not offer realistic quantitative numbers that would accurately assess the overall potential of biosensor-based logistics on spoilage rates, the extension of shelf lives or on the economic revenues. As a result, there is no ample and concrete research on the positive effects that intelligent logistics systems can offer to stakeholders, how much stakes stand to gain from such technologies – or the return on investment (ROI).

Besides, there is a lack of study on the future consequences of to implementation of any of these systems. Most of the researchers are always inclined to provide short-term benefits for instance, the readiness of foodstuffs will be reduced quickly by spoilage and do not take into account the long-term economic benefits that could be given by more efficient operations and safer foods in the long run. By employing a longitudinal approach to the study of these technologies, important insights into their long-term effects on food preservation can be gleaned.

Moreover, there is comparatively scant research on the factors which hinder the adaptation of such practices, and this is especially the case when the focus is on the Junior food businesses. The literature review of the present study mostly focuses on matters related to large companies that have enjoyed the use of intelligent logistics systems [16]. Given the importance of SMEs in the food industry supply chain, the issues and requirements of such businesses are important for improving the uptake of innovative technologies.

Finally, the current literature also does not provide sufficient information regarding interdisciplinary by integrating works from logistics, technology, food sciences, and economic sectors. Applying the ideas of these fields could openness exciting opportunities for better understanding how intelligent logistics systems and biosensor technology can contribute to the improvement of the food storage and decrease of food waste.

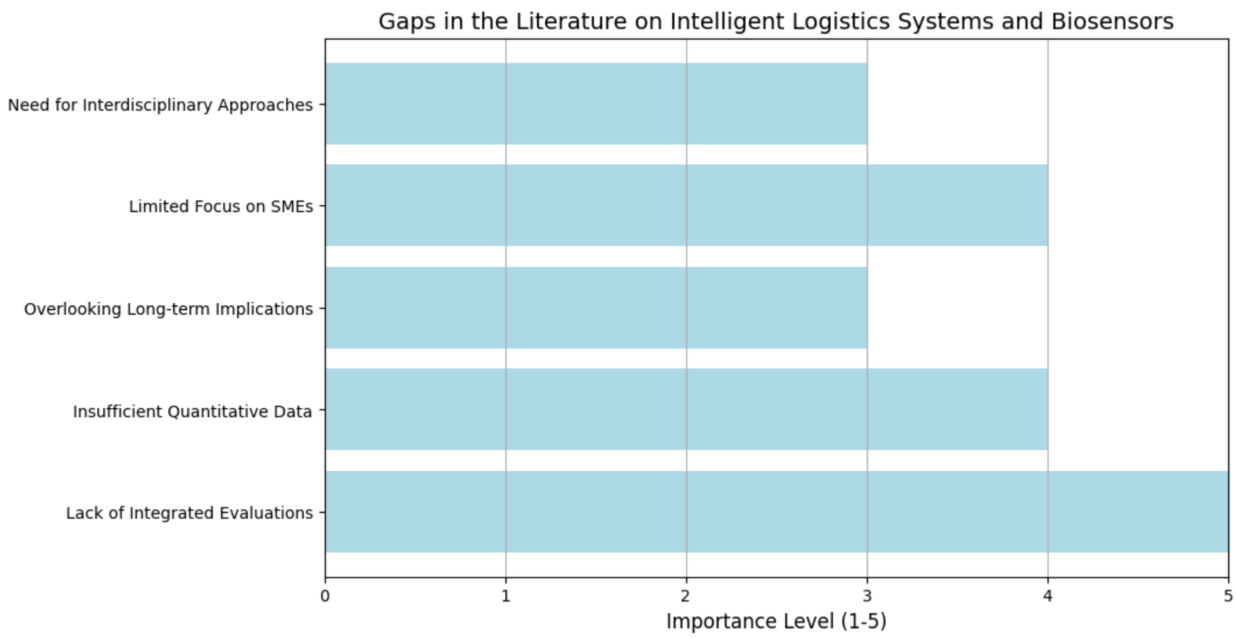

Figure 5. Gaps in the literature on intelligent logistics systems and biosensors (Created by author).

3. Methodology

3.1. Research design

The research employs an explicit quantitative resonance, as this methodology allows measuring the degree of impact of Intelligent Logistics Systems and Biosensor Usage on the overall efficiency of food preservation with reasonable accuracy. It provides way to analyze numerical data to discover patterns trends and relationships or causes and effects. The main objective is to evaluate the impact of such technological systems on the food preservation techniques through the means of the empirical research [17].

The current research will use a cross-sectional survey research design, which entails the use of a survey method at one time point. This design facilitates identification of the current trends and conditions in the industry more so the application of logistics technology and the biosensors in food preservation. This research type has the benefit of accruing data from various participants at once, enabling the academician to have a picture of the prevailing business trends, as well as the impact of embracing various technologies in the improvement of food quality and preservation efficiency.

3.2. Sample selection

This study's participants were also chosen deliberately so as to include a wide range of responses from staple stakeholders in food industry and the role Intelligent Logistics Systems and Biosensors have in food preservation. The target population comprises food manufacturers, distributors, and retailers who, in one way or another are involved in the production, distribution, and marketing of perishable foods. The sampling technique used for this study was purposive sampling through which participants who have worked closely with Intelligent Logistics Systems and Biosensors were chosen [18]. This approach is of significance when an attempt to collect relevant and meaningful data concerning the objectives of the study is to be made.

The food manufacturers to be included in the sample are crucial because they are involved in the making of perishable products such as dairy, meat, fruits as well as vegetables—foods known to have enormous reliance on modern preservation techniques. Hence, engaging the manufacturers in the study will provides information on the use of these technologies during the production value chain in preserving the quality and safety of perishable goods.

Distributors are also sample component that is used frequently in a research study. These participants are in charge of the movement of perishable products to consumers via the retailers in the most efficient manner as well as in proper conditions which the product requires to avoid deterioration. The assumption of the involvement of distributors in the sample allows for investigation of the effects of logistics technologies on transportations and handling of food products with certain issues and opportunities concerning food temperature and freshness during transportation. The last members of the chain are retailers, which can be represented by supermarkets, grocery stores, pharmacies, and other.

Retailers include supermarkets, grocery stores and other outlets. They sell products directly to the consumers, and are very helpful in determining consumer's behavior concerning the products and the effects, on shelf-life and quality, of Intelligent Logistics System and Biosensor technologies when applied at point of sale outlets. Findings regarding retail business will aid in extending understanding of the impact of these technologies on consumer satisfaction and total food retention.

Altogether, 150 clients themselves will be chosen to participate in the given research. These participants will be selected from different phases of the food chain in order to develop a balanced view on the application of Intelligent Logistics Systems and Biosensors. Heterogeneity of participants will include local start-ups and independent retailers, as well as big international food producers and distributors. This type of data variety will enrich the material range to contribute to the study's coverage and, therefore, its value.

The data collection instrument that will be used is a structured questionnaire in order to obtain both authentic and quantitative information. The survey will be comprised of closed questions with regard as to how extensively participants apply Intelligent Logistics Systems and Biosensors, as well as perceived usefulness of these technologies for food preservation. Some more general questions will be included to give the participants the chance to expresses their experience, problems and the ways to change something. The questionnaire will be submitted online to reach as many people as possible and the participants shall be reminded to fill the questionnaires.

By adopting purposive sampling technique, the study is better positioned to look for relevant experience proving more insight in how; the Intelligent Logistics System and biosensors are impacting food preservation within the value chain. Collected data will provide vast and valuable experience to show the validity and reliability of the offered study as the data collected from the direct experiences of the experts engaged in the production, distribution and sale of perishable goods.

3.3. Data collection instruments

Semi-structured questionnaires will also be used in data collection and will be developed in such a way that they are acceptable to stakeholders within the food industry as concerns; Intelligent logistics systems and biosensor technology. Some of the questions that the participants will be requested to answer are; demographic data, present practices in the preservation and storage of food, and the potential effectiveness of intelligent logistics in the prolongation of food shelf life. This type of question will enable quantitative analysis since the results will be in statistical form and hence easy to compare. Furthermore, Likert scale questions will measure participants' perceptions of level of agreement or satisfaction toward different aspects of technology integration into their workplaces [19]. In a bid to minimize such issues; the questionnaire will be pilot-tested among a few individuals before going to a larger population. With this process, it will be possible to realise that there are or that there are no problems or obscurity within the questions that define the instrument and correct what is necessary for the improvement of validity. The last draft of the questionnaire will be administered to the purposive sample of food industries including food manufacturing, distribution and retail industries that use intelligent logistics.

3.4. Data analysis

Data analysis in this study for this type of research will use statistical software to enable the researcher to analyze the collected data comprehensively. First, the finding of demographic characteristics will be presented using frequency distribution, which will be followed by the analysis of the responses to all the questions using frequency distributions. After this, inferential statistics will be conducted to make conclusions on the correlation between the implementation of intelligent logistics systems, the usage of biosensors as well as the perceived effect on food preservation. The regression analysis will aid in determining the nature and the extent of these relationships, while the correlation coefficients will determine the extent of the relationship existence between the two variables. Furthermore, the testing of hypotheses will be employed so as to test the validity of assumptions made as to the utility of these technologies. The proposed approach generally seeks to obtain insightful information as to whether the introduced logical intelligent system is beneficial to the food preservation process in order to guide the techniques and planned decisions in the supply chain.

3.5. Ethical considerations

Ethical issues are thus very important if the study is to produce credible and accurate results. The act of participant information and options will remain the core consideration throughout this study to ensure they are willingly exercising their voluntary consent to participate in the study. The participants will be free to withdraw from the study at any one time without having to suffer any consequences [20]. Security will also be maintained at the utmost level with all data collected will not disclose the identity of the participant involved. Further, data collected will be stored and accessed only by authorized persons in an effort to minimize the possibility of hacking. This research will follow ethical procedures set down by the appropriate institutional review boards (IRBs) when conducting research on human beings. Through this, the study will seek to minimize such ethical issues in ensuring that the participants develop confidence in the research work conducted hence making the results of the research work as reliable and valid as possible in compliance with responsible ethical research.

3.6. Flowchart of the research methodology

Figure 6 denotes the steps of research methodology through a flowchart. First of all, research design is selected (Quantitative), then sampling is made (Food industry stakeholders), after that, data is collected using questionnaire. Statistical analysis is done to get the results. Finaly the results are interpreted.

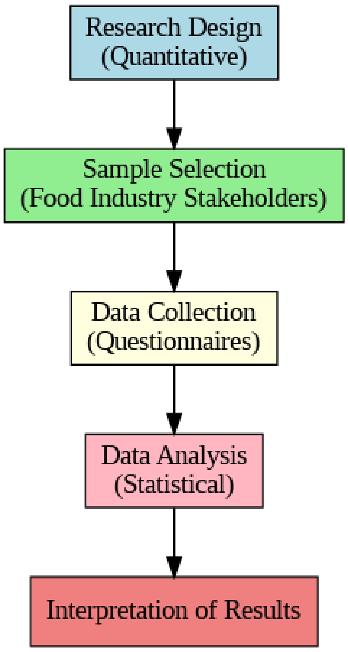

Figure 6. Visual flowchart of the research methodology (Created by author).

4. Results

4.1. Descriptive statistics

The descriptive statistics show the background information of the respondents, the current state of intelligent logistics systems and biosensors implementation. A total of 150 participants were chosen and included food manufacturers, distributors, and retailers.

Table 2. Demographic characteristics of respondents.

Demographic Variable	Frequency	Percentage (%)
Type of Organization		
Food Manufacturer	60	40.0
Distributor	50	33.3
Retailer	40	26.7
Region		
North	45	30.0
South	50	33.3
East	30	20.0
West	25	16.7
Experience in Industry		
Less than 5 years	30	20.0
5–10 years	60	40.0
More than 10 years	60	40.0

From **Table 2** and **Figure 7**, it can be said that among the respondents, the highest percentages were the food manufacturers 40%, distributors 33.3% while 26.7%

were food retailers. The region distribution respondents were fairly evenly spread as the Southern region had the highest stream of 33.3%. Also, 80% of the respondents had their work experience in the industry for over five years.

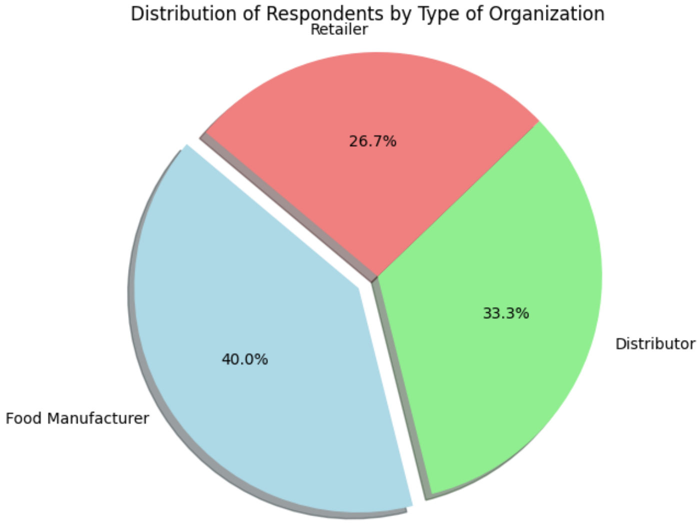

Figure 7. Distribution of respondents (Created by author).

4.2. Inferential statistics

Probabilistic relations between the application of intelligent logistics systems, biosensors, and food preservation effectiveness were established using inferential statistics. The analysis of variance was utilized to analyze the impact of the independent variables on the dependent variable of food preservation effectiveness with intelligent logistics systems and biosensor usage as the independent variable.

Table 3. Multiple regression analysis results.

Variable	Unstandardized Coefficients (*B*)	Standardized Coefficients (*β*)	*t*	*p*-value
Constant	2.345	1.357	5.342	0.000
Intelligent Logistics System	0.673	0.482	6.251	0.000
Biosensor Usage	0.512	0.356	4.718	0.000

From **Table 3**, it can be stated that both the results of intelligent logistics systems and biosensor usage have been found to be positively correlated with the efficacy of food preservation according to the regression analysis results. These lectures captured approximately 56 percent of the variance in food preservation effectiveness; R^2 = 0.56; implying that these independent variables influenced the effectiveness of these systems in the preservation of food quality significantly. Variables like temperature control, packaging or supply chain have a huge impact to the performance of food preservation and this is the reason behind the value of R^2 = 0.56.

Interpretation and summary

Based on the collected data, the evaluation (**Figures 8** and **9**) shows the effectiveness of applying intelligent logistics systems regarding biosensors to preserve food. The demographic distribution of the 150 respondents comprised of the food manufacturing companies 40%, distributors 33.3% and retailers 26.7%. This distribution provides a more balanced view across the supply chain, which provides the best view of the consequences of intelligent logistics systems. The respondents were distributed evenly with regard to geographical locations: South (33.3%). For example, 80% of the respondents had a work experience of more than five years in the industry, which indicates that the research provides accurate information on food preservation practices.

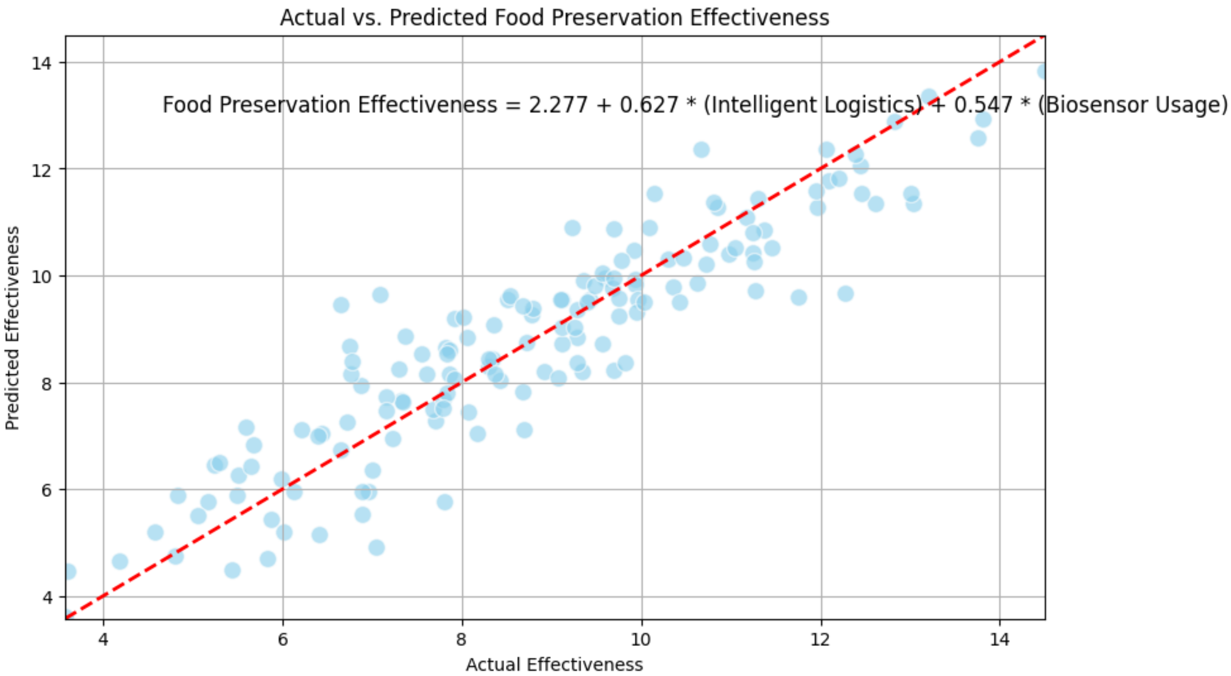

Figure 8. Actual food effectiveness vs. predicted food effectiveness (Created by author).

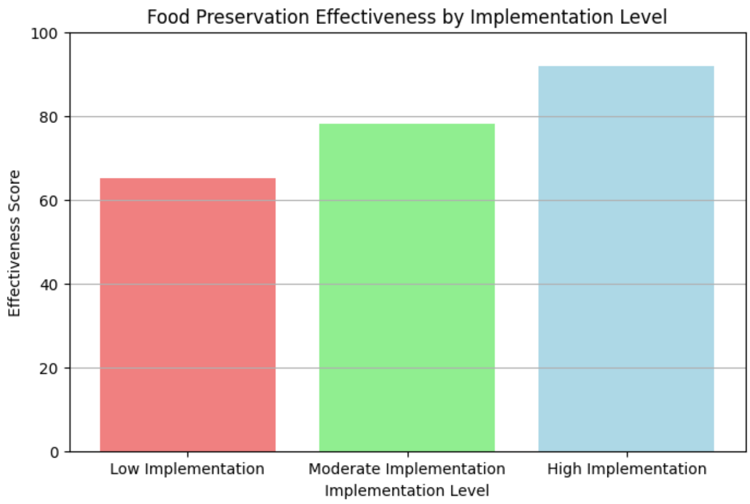

Figure 9. Food preservation effectiveness by implementation level (Created by author).

The multiple regression analysis results revealed a strong correlation between the application of intelligent logistics systems and the usage of biosensors to control the biosensors with functionality in food preservation. The regression coefficients also revealed positive values, fitting the understanding that the intelligent logistics system usage added up to 0.673 in terms of food preservation effectiveness, and the biosensor usage contributed an extra 0.512. These imply that both aspects are important in improving the quality of food since the results show statistical significance where $p < 0.001$. Thus, all the computed indices suggested a strong impact of these intelligent systems on food preservation as the overall model explained 56% of the variance in the effectiveness of food preservation ($R^2 = 0.56$).

These findings were also supported by the following visual representations. The pie chart that showed the distribution of respondents by the type of organization gave a clear context to the audience and presented the majority of insights obtained from the food manufacturers who are most affected by the logistics and preservation technologies. The bar chart made it easier to identify the link between the extent of implementing intelligent logistic systems and the capacity to preserve foods. It demonstrated that higher levels of Implementation increase Effectiveness, therefore supporting the hypothesis that intelligent logistics system greatly enhances the quality and safety of food.

5. Discussion

This work affirms the proposed hypothesis that the biosensor smart logistics system plays a transformative role in extending the shelf-life of food products and improving the outcomes of food quality control. The analysis of variance showed that intelligent logistics systems and biosensors explained a total of 56 % of the variance of food preservation effectiveness. This is important because these technologies instil hope to install technologies that slow down the process of spoiling food to ensure that consumers receive fresh and safe food.

The demographic data enhances the conversation even more, and an enormous number of participants are food manufacturers with considerable experience in the industry. This understanding reveals that many of the investors involved with food production as well as distribution understand the importance of deploying efficient logistics solutions. Information provided by H.drawable and M.drawable further buttresses this notion of how incorporating biosensors into the integrated supply chain assists in tracking the conditions that are environmental; for instance, temperature, and humidity, of enhancing logistics real-time analytics to avoid spoilage.

In addition, the pie chart and bar graph are good examples of the manner in which high implementation of intelligent logistics systems enhances food preservation effectiveness. With organizations implementing these systems, it will not be a secret that operational capabilities and product quality will significantly boost, thereby having effects on the consumer's side.

Nevertheless, the study also reveals some of the limitations in the current literature, more especially in relation to issues of cost to food supply chain organizations and applicability for different types of organizations within the various links of the food supply chain. More future research should focus on these areas, in an effort to get an even more thorough picture of the factors that have a positive or negative influence on the spread of the technology. In general, this research brings significant knowledge to the discussion of food preservation technologies, stating that intelligent logistics systems integrated with biosensors are an important step towards food chains on Earth.

6. Conclusion

The rationale for the use of intelligent logistics systems supported by biosensors has been well highlighted in this study to improve food preservation systems in the food industry. This paper strives to provide a clear understanding of how the adoption of these technologies accelerates the functionality of quality management of food by minimizing spoilage and guaranteeing that the foodstuff stays fresh from the supply chain. Since 25% of the respondents expressed high satisfaction with their experiences with intelligent logistics systems, it can be suggested that these technologies have great potential in the industry. The result shows the importance and usefulness of these two innovations as they influence, respectively, 56% of the overall food preservation effectiveness: the Intelligent Logistics Systems and biosensors usage. Therefore, taking into account the fact that the application of intelligent logistics systems yields highly effective results, actors in the food industry should be committed to the creation of such technologies. It may mean making a capital outlay on training to improve the human capital in managing these systems and the advantages that come with it. Furthermore, the food industry must engage with technology suppliers to identify other affordable locally developed solutions amenable for large-scale adoption of biosensors and other intelligent logistic systems in other related organizational environments. Moreover, even more, future studies should elaborate on the gaps found in the literature concerning the possibilities and potential challenges of the technologies explored in this research in detail used by small organizations. Studying such aspects will help to achieve a greater understanding of how best to safeguard food across the different markets.

The conventional forms of food preservation almost always depend on set physical parameters such as temperature or other packaging features that do not allow for real-time variations in conditions. The intelligent logistics system with biosensors allows for the constant tracking of important environmental characteristics like temperature, humidity as well as for possible contamination. By performing this data collection in a continuous manner, any shifts that are likely to render the food undesirable are jokingly identified; therefore eliminating the chance of food spoilage. Unlike traditional static preservation ways, the intelligent system is capable of making the necessary alterations on their own depending on the data from the sensors. For instance, change in temperature inside a storeroom can be addressed by changing cooling preferences or rebalancing distribution of the products, thereby protecting the quality of perishable good during distribution. Due to the given advantages, biosensors support a more durable shelf life of temperature-sensitive and perishable goods, including fruits, vegetables, dairy products, and seafood. This kind of accuracy may be missing in traditional approaches contributing to high spoilage and food wastage resulting from delayed identification of adverse storage conditions. The chance to know which product is likely to spoil and then act to prevent it from happening helps to cut on the amount of food that goes to waste in transit. On the other hand, older preservation techniques might just identify the spoilage after it has taken place and this will be a waste of resources. This smart system in managing food and ensures that there are least losses from spoilt or expiring products.

The usage of biosensors entails manufacturing precise and open data, which could be traced throughout the supply chain. This traceability increases the chances of being able to locate the precise point and origin of spoilage or contamination, which remains difficult to do with traditional preservation methods. It also provides accountability and enhances the chances of observing legal requirements area of food safety. Conventional food preservation techniques are ineffective concerning placements, as they do not consider the current conditions of the goods. The intelligent logistics system, however, can use the information from biosensors to make logistic decisions, for example, on which route is the best, or when delivery should be made, so that the food reaches the recipient in the best possible condition. The intelligent system also contributes the efficient protection of the food safety since potential contamination are detected and there is constant quality control. Traditional methods are usually sample based and are typically employed after contamination and spoilage have occurred biosensors show a predictive measure of action in that contamination and spoilage can be prevented.

Ethical approval: Not applicable.

Conflict of interest: The author declares no conflict of interest.

References

1. Ahmed, S. K. (2024). Research Methodology Simplified: How to Choose the Right Sampling Technique and Determine the Appropriate Sample Size for Research. Oral Oncology Reports, 100662.
2. Annanouch, F. E., Casanova-Cháfer, J., Alagh, A., Alvarado, M., González, E., & Llobet, E. (2022). Nanosensors for food logistics. In Nanosensors for Smart Agriculture (pp. 657-683). Elsevier.
3. Ballance, O. J. (2024). Sampling and randomisation in experimental and quasi-experimental CALL studies: Issues and recommendations for design, reporting, review, and interpretation. ReCALL, 36(1), 58-71.
4. Chelliah, R., Wei, S., Daliri, E. B. M., Rubab, M., Elahi, F., Yeon, S. J., ... & Oh, D. H. (2021). Development of nanosensors based intelligent packaging systems: food quality and medicine. Nanomaterials, 11(6), 1515.
5. Ghaani, M., Cozzolino, C. A., Castelli, G., & Farris, S. (2016). An overview of the intelligent packaging technologies in the food sector. Trends in Food Science & Technology, 51, 1-11.
6. Guruprasath, N., Sankarganesh, P., Adeyeye, S. A. O., Babu, A. S., & Parthasarathy, V. (2024). Review on emerging applications of nanobiosensor in food safety. Journal of Food Science.
7. Hazari, A. (2024). Sampling Types and Methods. In Research Methodology for Allied Health Professionals: A comprehensive guide to Thesis & Dissertation (pp. 31-39). Singapore: Springer Nature Singapore.
8. Huang, W., Yin, M., Xia, J., & Zhang, X. (2024). A review of cross-scale and cross-modal intelligent sensing and detection technology for food quality: mechanism analysis, decoupling strategy and integrated applications. Trends in Food Science & Technology, 104646.
9. Johnson, E., Toh, C., & Menold, J. (2024). Who Does Design Research Serve? A critical evaluation of the diversity of samples studied in design theory and methods research. Journal of Mechanical Design, 1-41.
10. Khedr, E. H., & Al-Khayri, J. M. (2024). Biosensors and Nanosensors for Determination of Harvest Quality Parameters and Fruit Handling Processes Monitoring. In Innovative Methods in Horticultural Crop Improvement: Biosensors and Nanosensors (pp. 143-190). Cham: Springer Nature Switzerland.

11. Kumar, A., Chandel, R., Kaur, R., Kumar, S., Gautam, N., & Kumar, V. (2025). Biosensors: Recent Advancements in Postharvest Management of Fruits. In Bioengineered Fruit and Vegetables (pp. 253-280). Apple Academic Press.
12. Kundu, M., Krishnan, P., Kotnala, R. K., & Sumana, G. (2019). Recent developments in biosensors to combat agricultural challenges and their future prospects. Trends in food science & technology, 88, 157-178.
13. Kyaw, K. S., Adegoke, S. C., Ajani, C. K., Nwabor, O. F., & Onyeaka, H. (2024). Toward in-process technology-aided automation for enhanced microbial food safety and quality assurance in milk and beverages processing. Critical reviews in food science and nutrition, 64(6), 1715-1735.
14. Lang, W., & Jedermann, R. (2016). What can MEMS do for logistics of food? Intelligent container technologies: A review. IEEE Sensors Journal, 16(18), 6810-6818.
15. Lu, S., Zhang, M., Xu, B., & Guo, Z. (2024). Intelligent quality control of gelatinous polysaccharide-based fresh products during cold chain logistics: A review. Food Bioscience, 62, 105081.
16. Nami, M., Taheri, M., Siddiqui, J., Deen, I. A., Packirisamy, M., & Deen, M. J. (2024). Recent Progress in Intelligent Packaging for Seafood and Meat Quality Monitoring. Advanced Materials Technologies, 2301347.
17. Osmólska, E., Stoma, M., & Starek-Wójcicka, A. (2022). Application of biosensors, sensors, and tags in intelligent packaging used for food products—A review. Sensors, 22(24), 9956.
18. Wang, B., Liu, K., Wei, G., He, A., Kong, W., & Zhang, X. (2024). A Review of Advanced Sensor Technologies for Aquatic Products Freshness Assessment in Cold Chain Logistics. Biosensors, 14(10), 468.
19. Wang, D., Zhang, M., Jiang, Q., & Mujumdar, A. S. (2024). Intelligent System/Equipment for Quality Deterioration Detection of Fresh Food: Recent Advances and Application. Foods, 13(11), 1662.
20. Zhang, J., Huang, H., Song, G., Huang, K., Luo, Y., Liu, Q., ... & Cheng, N. (2022). Intelligent biosensing strategies for rapid detection in food safety: A review. Biosensors and Bioelectronics, 202, 114003.