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Research Article

Food Adulteration And Its Detection Using Artificial Intelligence

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ABSTRACT

The food processing sector in India has witnessed remarkable growth in recent years, driven by government initiatives aimed at promoting private investment and infrastructure development. This paper provides an overview of the evolving regulatory framework governing food safety in India, with a focus on recent developments, challenges, and proposed reforms and different new technologies to curb food adulteration.. However, challenges such as delays in implementation and gaps in enforcement have highlighted the need for continuous improvement. The infamous 'Nestle-Maggi' dispute catalyzed reform, prompting the government to reassess existing regulations and strengthen enforcement mechanisms. Therefore, to protect human life new simple rapid approaches are needed to determine the concentration of adulterants in food products. In earlier, several approaches including spectroscopy, chromatography, ELISA are used for determination of adulterants. But these techniques are expensive, time-consuming, and require a skilled person to operate. Recently, nanotechnology-based techniques are successfully used for the identification of adulterates/contaminants. These techniques are simple and sensitive and avoid the use of costly instrumentation. Artificial Intelligence has been proved to be an advanced technology in food science and engineering. In this paper, we intend to proclaim the role of artificial intelligence in food adulteration detection in a systematic way. The potential for machine learning and deep learning in food quality has been analyzed through its applications. Various data sources that are available online to detect food quality have been discussed in this review. The different techniques used to detect food adulteration and the parameters considered while evaluating the food quality have been highlighted. The various comparisons have been done among the state-of-the-art methods along with their datasets sets and results. This study will assist the researchers in analyzing the best method available to detect food quality. It will help them in finding the food products that are studied by different researchers along with relevant future research directions

Keywords: Food safety, Regulation, FSSAI, India, Novel foods

INTRODUCTION

Over the past several years, the food processing industry in India has witnessed a remarkable growth trajectory, emerging as a sector ripe with potential for lucrative investments. This transformation has been fuelled by concerted efforts from the Ministry of Food Processing Industries, which has rolled out a series of strategic programs aimed at catalysing private investment and fostering sustainable development within the sector. These initiatives, designed to enhance infrastructure, bolster processing capacity, and provide essential support mechanisms, have been pivotal in propelling the food processing industry towards sustained growth.

The Ministry's initiatives represent a multifaceted approach towards nurturing the food processing sector, encompassing various facets crucial for its holistic development. One of the primary objectives of these programs is to address infrastructural deficiencies and create an enabling environment conducive to industry

expansion. By investing in infrastructure development, such as cold storage facilities, warehouses, and transportation networks, the government aims to mitigate logistical bottlenecks and enhance the efficiency of food supply chains. This strategic investment not only improves the storage and distribution capabilities of food products but also fosters greater integration with global markets, thereby bolstering the competitiveness of Indian food products on the international stage.

In addition to infrastructure development, the Ministry's initiatives focus on augmenting processing capacity across different segments of the food processing value chain. Through targeted interventions, such as the establishment of food parks, agro-processing clusters, and modernization of existing processing units, the government seeks to unlock the latent potential of India's agricultural produce and transform it into value-added products. By facilitating technology adoption, skill development, and innovation in food processing techniques, these initiatives aim to enhance productivity, quality, and profitability within the sector. Moreover, by promoting backward and forward linkages with farmers, agri-entrepreneurs, and retail chains, these programs foster greater inclusivity and equitable growth within the food processing ecosystem.[1]

A cornerstone of the Ministry's approach towards industry development is its emphasis on attracting foreign direct investment (FDI) to fuel sectoral growth. Recognizing the critical role of FDI in augmenting capital inflows, technological expertise, and global best practices, the government has adopted a liberalized policy framework to facilitate foreign investments in the food processing sector. Under the automated route, foreign investors can now avail themselves of 100 per cent FDI in the food processing industry, thereby unlocking new avenues for international collaboration, technology transfer, and market access. This proactive stance towards FDI underscores India's commitment to fostering a business-friendly environment that incentivizes foreign participation and promotes economic prosperity.[2]

Moreover, alongside efforts to attract foreign investments, the Ministry has embarked on a journey of regulatory reform aimed at enhancing the governance and oversight of the food processing industry. Recognizing the importance of a robust regulatory framework in safeguarding consumer interests, ensuring food safety, and promoting industry compliance, the government has undertaken comprehensive measures to strengthen regulatory mechanisms and streamline regulatory processes. These efforts encompass a wide range of initiatives, including the revision of existing regulations, the introduction of new standards, and the deployment of advanced regulatory technologies to improve monitoring and enforcement capabilities.

The overarching objective of these regulatory reforms is to create a transparent, predictable, and investor-friendly regulatory environment that instils confidence among stakeholders and fosters responsible business conduct. By aligning regulatory frameworks with international best practices, harmonizing standards, and promoting industry self-regulation, the government aims to enhance the ease of doing business in the food processing sector while safeguarding public health and consumer interests.

The food processing industry in India represents a compelling investment opportunity, propelled by robust government support, favourable policy frameworks, and a conducive business environment. The Ministry of Food Processing Industries' strategic initiatives, encompassing infrastructure development, capacity augmentation, FDI promotion, and

regulatory reform, underscore the government's unwavering commitment to unleashing the sector's full potential. As India embarks on its journey towards becoming a global food processing hub, investors stand to benefit from the myriad opportunities presented by this dynamic and rapidly evolving industry.[3]

WORK-IN-PROGRESS

The Food Safety and Standards Act and the regulations that correspond to it include a number of parts that are inconsistent with one another. The conflicts may develop as a result of the fact that the implementation of the law takes place in a number of phases, with different groups of persons participating in each step. When it comes to its position, the FSSAI sometimes displays inconsistency. As an example, the FSSAI has modified its attitude on the

registration and licencing requirements for exporters and e-commerce platforms, even though the current law has not been updated. The FSSAI is proven to be adaptable in its attitude, according to a different point of view, provided that sufficient justifications are supplied in advance. India, which is comprised of 28 states and eight union territories, poses a number of issues when it comes to the implementation of laws by the state food authorities. It is because the state food authorities do not get enough training on the amended laws and regulations that food businesses are experiencing unnecessary difficulties. Because of this, it is essential to have a solid understanding of their constraints and to effectively handle the issue. As of right now, the

[1] Kohli, Charu, and Suneela Garg. "Food safety in India: an unfinished agenda." *MAMC Journal of Medical Sciences* 1, no. 3 (2015): 131-135.

[2] Kristkova, Zuzana Smeets, Delia Grace, and Marijke Kuiper. “The economics of food safety in India: a rapid assessment.” Wageningen University & Research, (2017).

[3] Singh, S. P., S. Kaur, and D. Singh. "Toxicological profile of Indian foods—ensuring food safety in India." In Food Safety in the 21st Century, pp. 111-127. Academic Press, (2017).

process of upgrading state-level laboratories is still going on, and it may take some more time to finish. In addition, the permission of the Parliament is still being sought for other amendments that have been recommended in accordance with the FSS Act and its regulations. As a result of the adoption of these adjustments, it is envisaged that the regulatory framework will become much more simplified.

FSSAI PROPOSES OVERHAUL OF FOOD SAFETY REGULATIONS FOR STREAMLINED COMPLIANCE IN INDIA'S FOOD INDUSTRY

In order to improve the efficiency of business procedures within India's food industry, the FSSAI has suggested a significant revision of the regulations that govern food safety and standards to be implemented across the nation. It was a crucial step towards establishing the

'One Nation, One Commodity, One Regulator' framework that the proposals were considered during the 43rd meeting of the FSSAI, which was headed by Apurva Chandra, who is the Union Health Secretary.[4]

FSSAI Certification Takes Centre Stage: The FSSAI has taken a big step by announcing that its certification is the sole mandatory requirement for food goods throughout the country. This move is intended to simplify compliance procedures and expedite regulatory processes. Following the implementation of this key decision, food businesses will no longer be required to get additional certifications from organisations such as the Bureau of Indian Standards (BIS) or AGMARK.[5] Businesses in the food sector are anticipated to see a considerable decrease in complexity as a result of the simplification of their obligations in order to conform to the standards that have been developed by a single regulatory body.

Approval of Standards and Amendments: The significant gathering also saw the endorsement of many standards and modifications, covering areas such as mead (Honey wine), alcoholic ready-to-drink drinks, milk fat products, and rules for haleem, a traditional meal consisting of meat, pulses, grains, and other components.[6] The regulation amendments highlight the FSSAI's strong dedication to maintaining high standards of food safety for a wide range of food items.

Regulatory Compliance and Stakeholder Engagement: Alongside these changes, the FSSAI approved extensive guides that provide detailed instructions on analysing various food items to guarantee compliance with regulations. These documents are essential tools for firms aiming to comply with FSSAI regulations. Prior to formalising these recommendations and notifying the gazette, they must undergo feedback from stakeholders. The iterative process demonstrates the FSSAI's commitment to openness and the active involvement of stakeholders in influencing the development of food safety standards.

The FSSAI's strategic plan signifies a significant advancement in the integration of food safety laws. If effectively executed, these suggested modifications possess the capability to initiate a novel period of effective and efficient regulation within India's food sector, hence

benefiting companies via the reduction of regulatory duplications and the simplification of compliance procedures.

FUNCTIONING OF FOOD SAFETY AND STANDARDS AUTHORITY OF INDIA

Regulatory framework: The Committee observed that despite the Food Safety and Standards Act, 2006 being in effect for over ten years, FSSAI has not yet established regulations regarding the accreditation of food testing laboratories, food labelling standards, and genetically engineered food, among other matters. In addition, the FSSAI has not been able to identify the specific areas where standards still need to be developed or revised. A majority of states lack a distinct food safety agency to effectively enforce food safety regulations and standards. The consequences of this situation include (i) the absence of rigorous quality control measures, (ii) food contamination, (iii) deceptive packaging, and (iv) the distribution of faulty food items.[7]

The Committee advised that the FSSAI should establish and officially announce rules on all specified areas included in the Act within a one-year timeframe. In addition, it suggests the creation of an independent food safety agency in each state to enforce a strong food safety system.

Licensing and registration: in accordance with the Act, it is a violation of the law for any person to initiate or run a food business without first obtaining a licence. Based on their observations, the Committee found that a significant number of food enterprises were operating either without a valid licence or with

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[4] Pillay, D. Padma Kumar, and TK Manoj Kumar. "Food security in India: Evolution, efforts and problems." *Strategic analysis* 42, no. 6 (2018): 595-611.

[5] Vasanthi, S. I. R. U. G. U. R. I., and Ramesh V. Bhat. "Management of food safety risks in India." *Procs Indian Nat Acad Sci* 84 (2018): 937-43.

[6] Singh, Rameshwar, and Anil Kumar Puniya. "Role of Food Safety Regulations in Protecting Public Health." *Indian Journal of Microbiology* (2024): 1-3.

[7] Kamboj, Sahil, Neeraj Gupta, Julie D. Bandral, Garima Gandotra, and Nadira Anjum. "Food safety and hygiene: A review." *International Journal of Chemical Studies* 8, no. 2 (2020): 358-368.

licences that had expired. Furthermore, many national and state licencing organisations were issuing licences based on documents that were lacking in quality. Furthermore, it was noted that the percentage of licences that are refused for renewal is quite low throughout the renewal process. The Committee advised FSSAI to evaluate all licences granted under the previous system of product approvals and to revoke and reissue licences as necessary in accordance with the current mechanism of product approvals.

Food safety surveys: The Committee noted that FSSAI has delegated the responsibility of conducting surveys to states; however, governments lack the necessary resources and
capabilities to carry out these surveys. Nevertheless, there has been no survey done to assess the implementation of the Act. FSSAI lacks a comprehensive database of food firms. Hence, FSSAI and state food agencies should carry out surveys of food enterprises under their jurisdiction.

Food recall plans: The Committee advised FSSAI to guarantee that every food firm have a food recall strategy, to be implemented in the event of a prohibition on any food goods. In addition, it is suggested that FSSAI should regularly issue recall reports every two weeks in order to inform customers of contaminated and misbranded goods.

Food testing laboratories: The Committee observed a scarcity of labs, personnel, and operational food testing equipment in the majority of food laboratories used by FSSAI and
state food safety agencies. There is an insufficient amount of testing done on food samples. There are a total of 266 laboratories in the country; however, a sizeable portion of them do not possess the requisite equipment to analyse essential features such as the presence of heavy metals, pesticides, and microbiological contamination. To obtain accurate results, the Committee suggested implementing a uniform testing process throughout the whole country. Additionally, it is recommended that every state develop its hiring criteria and routinely oversee the administration of tests in order to fill open positions in laboratories.

The Committee made the observation that just thirteen of the sixty-two state food labs that are now in operation have accomplished the task of obtaining accreditation from the National Accreditation Board for Testing and Calibration Laboratories. Taking into consideration this specific framework, the Committee has said that it is essential to mandate certification for all laboratories in order to provide efficient quality control of food for consumption.

Amendments to the Act: The Committee proposed many revisions to the current Food Safety and Standards Act, 2006 in order to create a consistent regulatory system for food safety across the nation. The proposals pertain to three areas: (i) the regulation of food colour use, (ii) the regulation of pesticide usage in primary production by farmers and fishermen, and (iii) the modification of the procedure for selecting the Chairman and CEO of FSSAI to include experts and scientists from the food industry.

Shortage of manpower: The Committee noted a severe deficiency of personnel at both FSSAI and state safety agencies, resulting in a detrimental impact on food safety measures across the states. The Ministry of Health and Family Welfare should develop a coordinated action plan with the states to address the scarcity of workforce.

FOOD ADULTERATION AND ITS DETECTION THROUGH ARTIFICIAL INTELLIGENCE

Understanding Food Adulteration

Food adulteration refers to the deliberate addition, substitution, or contamination of food products with inferior or harmful substances. This practice is often carried out to increase profit margins, extend shelf life, or deceive consumers. However, it poses severe risks to public health, leading to illnesses, long-term health issues, and sometimes even fatalities. Common types of food adulteration include:

- **Substitution**: Replacing a high-quality ingredient with a cheaper, lower-quality one.
- **Addition of Harmful Substances**: Introducing non-food grade chemicals, dyes, or preservatives.
- **Dilution**: Mixing a food product with water or other substances to increase volume.
- **Mislabeling**: Providing false information about the origin, quality, or contents of the food product.

Given the complexity and scale of modern food supply chains, detecting food adulteration has become increasingly challenging. Traditional methods, while effective, often involve time-consuming and labor-intensive laboratory tests. This is where Artificial Intelligence (AI) comes into play as a revolutionary tool for enhancing the detection of food adulteration.

AI in the Detection of Food Adulteration

AI offers cutting-edge solutions for detecting food adulteration with greater speed, accuracy, and efficiency than conventional methods. Here are some ways AI is transforming food adulteration detection:

1. **Advanced Spectroscopy and Imaging**:
   - AI enhances the analysis of data from advanced spectroscopy techniques like Near-Infrared (NIR) and Raman spectroscopy. By applying machine learning algorithms, AI can detect subtle differences in the spectral data that may indicate the presence of adulterants. This allows for rapid, non-destructive testing of food products.

2. **Pattern Recognition**:
   - AI excels at recognizing patterns in complex datasets. In food adulteration detection, AI models can be trained on large datasets containing information on authentic and adulterated food samples. Once trained, these models can accurately identify adulteration in new samples by recognizing deviations from established patterns.
3. **Real-Time Monitoring**:
   - AI-powered sensors and IoT devices can be integrated into food production lines to continuously monitor for signs of adulteration. These systems can detect anomalies in real time, such as unexpected changes in chemical composition or physical properties, triggering immediate alerts and actions to prevent contaminated products from reaching the market.
4. **Big Data Analytics**:
   - The food industry generates vast amounts of data from various sources, including supply chain records, quality control checks, and market data. AI can analyze this big data to identify trends, correlations, and potential risks related to food adulteration. This enables companies and regulators to predict and mitigate adulteration risks before they materialize.
5. **Blockchain Integration**:
   - AI, combined with blockchain technology, can enhance the traceability of food products across the supply chain. Blockchain ensures that all transactions and movements of food products are recorded in an immutable ledger, while AI can analyze this data to detect inconsistencies or suspicious activities that may indicate adulteration.
6. **Smartphone Applications**:
   - AI-driven mobile applications are increasingly being developed to empower consumers to detect food adulteration themselves. By scanning product barcodes or using smartphone cameras, consumers can access AI-powered databases that analyze the product's ingredients and history, providing instant information on its authenticity and safety.

Benefits of AI in Food Adulteration Detection

- **Speed and Efficiency**: AI can process and analyze large volumes of data quickly, significantly reducing the time required for adulteration detection.
- **Accuracy and Precision**: Machine learning models can detect even trace amounts of adulterants, offering higher accuracy than many traditional methods.
- **Cost-Effectiveness**: By automating detection processes, AI reduces the need for expensive and time-consuming laboratory tests.
- **Scalability**: AI systems can be easily scaled to monitor large-scale food production and supply chains, ensuring consistent quality control.

AI'S ROLE IN IMPROVING FOOD SAFETY

Food adulteration is a significant concern that affects public health, the food industry, and regulatory bodies worldwide. Adulteration refers to the addition of substances to food items in order to increase quantity or preserve them longer, often compromising quality, safety, and nutritional value. This malpractice can lead to severe health issues, including foodborne illnesses, chronic diseases, and even death. Addressing food adulteration effectively requires advanced technologies that can detect, monitor, and prevent these practices efficiently.

Artificial Intelligence (AI) has emerged as a powerful tool in combating food adulteration. AI offers innovative solutions to identify and mitigate adulteration through its ability to analyze vast amounts of data, recognize patterns, and make accurate predictions. The introduction of AI in food adulteration encompasses various applications, including:

1. **Detection and Analysis**:
   - AI-powered systems can analyze food samples to detect contaminants and adulterants with high precision. Machine learning algorithms, combined with advanced sensors and imaging techniques, can identify even trace amounts of harmful substances, ensuring the safety and quality of food products.
2. **Quality Control**:
   - AI enhances the efficiency of quality control processes in the food industry. Automated systems equipped with AI can continuously monitor the production process, detecting any irregularities or signs of adulteration in real time. This allows for immediate corrective actions, reducing the risk of compromised products reaching consumers.
3. **Supply Chain Transparency**:
   - AI enables better tracking and traceability within the food supply chain. By leveraging blockchain technology and AI-driven analytics, stakeholders can ensure the authenticity and integrity of food products from farm to table. This helps in identifying and eliminating sources of adulteration at any point in the supply chain.

4. Predictive Analytics:
- AI can predict potential adulteration risks by analyzing historical data, market trends, and other relevant factors. This proactive approach allows regulators and food companies to implement preventive measures, reducing the likelihood of adulteration incidents.

5. Consumer Awareness:
- AI-driven applications, such as mobile apps, can empower consumers to check the authenticity of food products by scanning labels or barcodes. These apps can provide instant information about the product's origin, ingredients, and potential adulteration risks, enabling informed purchasing decisions.

AI is significantly enhancing food safety and regulatory frameworks in various areas of the food supply chain, including production, processing, distribution, and consumption. AI plays a crucial role in identifying and stopping harmful substances by combining high-resolution photography with AI to detect foreign items, spoilage, and flaws beyond existing methods. Manufacturing lines install AI-enabled cameras and sensors to oversee and scrutinize food products for impurities or harmful substances, ensuring prompt identification and elimination of dangerous goods. AI models use predictive analytics to examine past and current data forecasting possible instances of contamination and enabling proactive actions to avert epidemics.[8]

AI enhances food safety by improving traceability throughout the supply chain, a crucial aspect for effectively monitoring the origin of contamination and handling recalls. Combining AI with blockchain technology creates a secure and unalterable record of the entire food item process, improving transparency and responsibility. AI-driven "radio-frequency identification" (RFID) and Internet of Things (IoT) sensors monitor and record environmental conditions, ensuring adherence to safety regulations and maintaining product quality.

AI assists regulatory agencies and enterprises in adhering to food safety laws by automating and optimizing monitoring procedures. AI technologies provide automated reports that analyze large volumes of data to verify ongoing adherence to food safety requirements. AI's Natural Language Processing (NLP) skills enable it to analyze and comprehend new legislation, ensuring organizations remain updated on changes and can adjust promptly.

AI-powered apps are enabling customers to make more secure food choices and stay well-informed about food safety concerns. AI-driven mobile applications provide up-to-date data on food recalls, allergy notifications, and nutritional details, empowering customers to make well-informed choices. However, there are challenges to AI's extensive use, such as maintaining superior and uniform data across the supply chain, implementation being prohibitively expensive, and ethical and privacy concerns arising from the use of AI in surveillance and data gathering.[9]

The production of food from agricultural products requires the use of both rigorous scientific principles and precise technical techniques. Food processing enterprises generate vast quantities of data during their operations. Data is essential for the efficient functioning of logistical networks, processing equipment, and ensuring food safety. Statistical approaches may be used to analyse daily data, and the findings can be succinctly summarised for various purposes.

This data can be divided into three types:

1. Structured data such as numerical information, times and dates, serial numbers, etc.
2. Unstructured data such as text, email correspondence, machine data, survey replies, and transcripts
3. Semi-structured data such as tables, graphs, PowerPoint presentations, transcripts, audio and video files, XML documents, etc.

All three categories of data together have some traits in common, such as:

- Volume: Every food processing plant and every food-related corporation has enormous amounts of data stored in their databases.
- Value: The resident data contains a lot of useful information, in order to be useful to operations and decision-makers, these insights must be found, extracted, and processed.
- Variety: A wide range of big data types can be analyzed separately or collectively to look for any more significant patterns, trends, or correlations
- Velocity: Large data can be examined historically, but depending on the situation, it can also be examined in real-time. For example: Sensors are being installed in food processing plants to collect data at very high speeds. For quick answers, traditional analytical methods are frequently insufficient.

[8] Qian, C., S. I. Murphy, R. H. Orsi, and M. Wiedmann. "How can AI help improve food safety?" *Annual Review of Food Science and Technology* 14 (2023): 517-538.

[9] Karanth, Shraddha, Edmund O. Benefo, Debasmita Patra, and Abani K. Pradhan. "Importance of artificial intelligence in evaluating climate change and food safety risk." *Journal of Agriculture and Food Research* 11 (2023): 100485.

Insider threats are becoming increasingly dangerous for enterprises because they may have a negative effect on physical security, food defence, brand reputation, and food product safety. For instance, enterprises may employ real-time or nearly real-time data updates to identify system abnormalities and potentially uncover any attempts by a disgruntled employee to disrupt an ongoing operation. A method of managing data involves using AI to assist those responsible for data analysis.[10]

Using AI to Process Data for Food Safety

- Machine learning: The systems are able to improve with time as a result of their ability to learn. It is useful for sifting through large datasets in search of patterns, outliers, and trends pertaining to food safety. As a result, it may be used to predict potential food poisoning epidemics by analysing past data and current environmental conditions.
- Natural language processing: Computers can now understand, interpret, and even create their own language thanks to this development. This aids in the detection of possible food safety and consumer sentiment issues by use of text data analysis from sources including social media, reviews, and regulatory regulations.
- Computer vision technology: It helps in interpreting and comprehending visual data, including images and videos. It can also be used for checking food contaminants, and spoilage.
- Deep learning: It can be applied to enhance predictive models for food safety incidents and to improve image recognition during food quality inspections.

Here are some instances of how various AI can be applied to big data analytics for food safety utilizing currently accessible technologies

1. Analytical prediction
2. Quality assurance and verification
3. Transparent supply chain
4. Social media monitoring and sentiment analysis
5. Adherence to regulations
6. Tailored food safety guidelines

AI Bio surveillance:

In the future, artificial intelligence will have an increasing impact on food safety. Biological threats may emerge inadvertently or intentionally. Biomonitoring is beneficial for both public safety (by preventing deliberate food adulteration and bioterrorism) and public health (by preventing foodborne disease). Using logistical networks, AI-assisted bio surveillance systems have the potential to integrate into all stages of the food chain, including pre-harvest and post-harvest. Every sensor or analyser that interacts with a human-consumed agricultural product will produce a unique set of data. AI may then merge and analyse this data. We may design the application to search for specific patterns and correlations, thereby identifying tainted product molecules. Additionally, it can detect new abnormalities in processes or outputs that may have gone unnoticed before.[11] Subsequently, Subject Matter Experts (SMEs) and system operators would be able to promptly access the real-time AI discoveries and evaluate them. Human participation is essential for determining analysis using logic, experience, and judgement. The AI-powered analytical system can integrate structured, unstructured, and semi-structured data to facilitate analysis. Ultimately, we can accurately state that AI-assisted analytics is a rapidly advancing domain that, with proper attention, can protect public health, reduce the likelihood of foodborne diseases, and maintain brand excellence and profitability. Exercising prudence is necessary when adopting this technology. However, with successful deployment and appropriate calibration, AI can help users gain deeper insights into their own products and processes. This offers the opportunity to uncover concealed problems and identify new ways to enhance efficiency. [12]

CONCLUSION

The regulatory landscape governing food safety in India has undergone significant evolution over the years, reflecting the nation's commitment to ensuring the quality and safety of food products consumed by its citizens. From the enactment of the Food Safety and Standards Act, of 2006, to the recent proposals for regulatory overhaul by the FSSAI, the journey has been marked by both challenges and progress.

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[10] Awuchi, Chinaza Godswill. "HACCP, quality, and food safety management in food and agricultural systems." *Cogent Food & Agriculture* 9, no. 1 (2023): 2176280.

[11] Holzinger, Andreas, Katharina Keiblinger, Petr Holub, Kurt Zatloukal, and Heimo Müller. "AI for life: Trends in artificial intelligence for biotechnology." New Biotechnology 74 (2023): 16-24.

[12] Agrebi, Said, and Anis Larbi. "Use of artificial intelligence in infectious diseases." In *Artificial intelligence in precision health*, pp. 415-438. Academic Press, 2020.

The foundation of the modern regulatory framework was laid with the introduction of the Food Safety and Standards Act, of 2006, which replaced the fragmented system of regulations previously governing the sector. This landmark legislation led to the establishment of the FSSAI, tasked with monitoring and regulating various aspects of food production, storage, import, and sale. However, the initial implementation of the Act faced hurdles, including delays in issuing regulations and challenges in aligning with evolving industry practices. The infamous 'Nestle-Maggi' dispute served as a wake-up call, highlighting gaps in the regulatory framework and prompting a re-evaluation of existing practices.

The evolving regulatory framework also addresses the emergence of novel food products, including plant-based alternatives and genetically modified foods. While these innovations hold promise for addressing various consumer needs and preferences, they also pose unique regulatory challenges.

The introduction of specific regulations, such as the Food Safety and Standards (Vegan Foods) Regulations, 2022, demonstrates a willingness to adapt to changing market dynamics
while ensuring consumer safety. However, concerns remain regarding the discretionary powers wielded by regulatory authorities and the need for greater clarity and transparency in the regulatory process.

Moving forward, collaboration between industry stakeholders, regulatory authorities, and policymakers will be crucial for navigating the complex regulatory landscape and fostering innovation while upholding stringent safety standards. This includes continued investment in
infrastructure, capacity building, and technology adoption to enhance regulatory oversight and ensure compliance. While India's food safety regulatory model has made significant strides in recent years, there is still work to be done to address existing challenges and adapt to evolving industry trends. By embracing a holistic approach that balances innovation with safety, India can establish itself as a global leader in ensuring the quality and integrity of its food supply chain.