International Journal of Advance and Innovative Research
Volume 13, Issue 1 (XIII): January – March 2026
ISSN 2394 - 7780

DETECTION OF ADULTERANTS IN SPICES AND EDIBLE OILS: A SYSTEMATIC LITERATURE REVIEW OF BIOLOGICAL AND BIOSENSOR-BASED METHODS

Honey Ajay Yadav[1]* and Shweta Vijay Khopde[2]
[1,2]Department of Biotechnology, Laxmi Charitable Trust's, Sheth L.U. Jhaveri College of Arts and Sir M.V. College of Science and Commerce, Andheri East, Mumbai, India
[1]honeyaartiyadav@gmail.com, [2]khopdesv@gmail.com
Corresponding author: Honey Ajay Yadav, honeyaartiyadav@gmail.com

ABSTRACT
Adulteration of spices and edible oils remains a significant global food safety concern due to their high commercial value and widespread consumption. The intentional addition of cheaper substitutes, synthetic dyes, mineral oils, and other unauthorized substances not only compromise product quality but also poses serious health risks to consumers. This systematic literature review critically evaluates existing detection strategies for adulterants in spices and edible oils, with particular emphasis on conventional analytical methods, biosensor-based technologies, and emerging biological approaches. While chromatographic and spectroscopic techniques demonstrate high sensitivity and reliability, their dependence on sophisticated instrumentation, skilled personnel, and high operational costs limits their applicability for rapid and decentralized monitoring. Biosensor-based systems offer faster response times and improved portability; however, challenges related to stability, scalability, and standardization remain. Notably, microorganism-based and paper-strip detection methods emerge as promising low-cost and environmentally sustainable alternatives for preliminary screening applications. Despite encouraging laboratory findings, these approaches require further validation in real food matrices and regulatory integration. The review identifies critical research gaps and highlights the need for affordable, field-deployable detection systems that can strengthen regulatory surveillance and enable consumer-level screening. Overall, this study provides a comprehensive synthesis of current technologies and outlines future directions for developing accessible and scalable adulteration detection strategies.

Keywords*: Food adulteration; Spices; Edible oils; Biosensors; Microorganisms; Paper-strip detection; Systematic literature review.*

1. INTRODUCTION
Spices and edible oils are integral components of daily diets across the world and play a vital role in nutrition, food flavoring, and culinary practices (Kumar et al., 2019; Ali et al., 2019). Their high commercial value, combined with increasing global demand, has made them particularly susceptible to adulteration practices. Multiple studies reviewed in this work report that adulteration of edible oils commonly involves blending with cheaper vegetable oils, mineral oils, or animal fats, while spice adulteration often includes the addition of synthetic dyes, brick powder, sawdust, or exhausted spices (Singh et al., 2020; Gupta & Bansal, 2021; Kumar et al., 2020). These practices are primarily driven by economic incentives and weak surveillance mechanisms in informal food markets. Several of the reviewed papers emphasize that adulteration in edible oils such as mustard oil, olive oil, and ghee is particularly difficult to detect using sensory evaluation alone (Ali et al., 2019; Patel & Mehta, 2021). Instrumental studies demonstrate that even small proportions of adulterants can significantly alter fatty acid profiles and thermal properties, yet remain undetectable by consumers. Similarly, spice adulteration using non-permitted colorants such as Sudan dyes poses severe health risks, including carcinogenic effects, as highlighted in multiple toxicological assessments (Kumar et al., 2020; Shah et al., 2020). The literature further indicates that existing regulatory frameworks rely heavily on laboratory-based analytical techniques (FAO/WHO, 2018; Patel & Mehta, 2021). Although these methods are scientifically sound and accurate, they are quite expensive in terms of money, equipment, and expertise, and therefore not suitable for small or local monitoring centers. Studies published in food safety and biosensor journals consistently report that the lack of rapid screening tools contributes to delayed detection and increased exposure risk. This challenge is particularly pronounced in developing countries, where access to advanced analytical infrastructure is limited. Recent research trends show a growing interest in alternative detection strategies that are rapid, cost-effective, and deployable at the point of need (Rao et al., 2021; Mishra et al., 2023; Yadav & Mishra, 2023). Biosensor-based approaches, including enzyme-based, immunosensor, and nanobiosensor systems, have been extensively discussed in the reviewed literature as emerging solutions. In parallel, several studies report the potential of biological systems, including microorganisms, as natural indicators of chemical toxicity and food quality deterioration. These biological responses form the basis for developing simplified detection platforms. Despite these advances, the reviewed literature reveals a clear gap in the translation of biological detection mechanisms into simple, user-friendly formats such as paper-strips (Sharma & Kaur, 2021;

ISSN 2394 - 7780

Chandra et al., 2022). Most microorganism-based studies remain at the laboratory proof-of-concept stage and lack systematic validation in real food matrices.

Therefore, this systematic literature review aims to critically analyze existing detection methods, synthesize findings across studies, and identify research gaps with specific focus on biological and microorganism-based paper-strip detection of adulterants in spices and edible oils.

2. REVIEW METHODOLOGY

This study employed a systematic literature review methodology to ensure transparency, reproducibility, and analysis of available literature on the detection of adulterants in spices and edible oils. The approach to carrying out this literature review was designed in compliance to guidelines related to systematic literature reviews in food sciences and biosensor research in view, in order to identify and analyze relevant literature studies, especially on the use of biological and biosensor-based methods for detection.

2.1 Databases and Search Strategy

An extensive search of major scientific databases, including PubMed and Google Scholar, was conducted to identify relevant studies on adulterant detection technologies. Articles on detection technologies published between 2010 and 2023 in English were considered for inclusion in this study.

The approach for searching the literature consists of keywords and Boolean logic techniques. The keywords and Boolean logic utilized for this systematic review include food adulteration, edible oil adulteration, spice adulteration, biosensors, biological detection, microorganisms, and rapid detection techniques. These keywords were used individually and in combination, such as “spice adulteration AND biosensors” and “edible oil adulteration AND microorganisms.”

2.2 Study Selection Process

Initially, an extensive list of articles related to research was obtained from the initial database search. Subsequently, any duplicate articles were manually removed. Then, the titles and abstracts of these articles were used for evaluation based on their relevance to the goals of the systematic review. The articles were then critically evaluated based on certain criteria.

Although a PRISMA flow diagram is not included, the study selection process followed the core principles of PRISMA guidelines including identifying studies to screen, screening studies to check eligibility, and selecting studies for final evaluation.

2.3 Inclusion and Exclusion Criteria

To ensure the quality and relevance of the chosen literature, the following criteria were applied:

Inclusion criteria:

1. Peer-reviewed original research articles and review papers
2. Studies pertaining to detection of adulterants in spices and edible oils
3. Articles employing chemical, instrumental, biological, or biosensor detection methods

Relevant studies with adequate methodological and analytic detail

Exclusion criteria:

1. Non-English language
2. Studies Not Related to Food Adulteration
3. Articles without clear methodology or outcome description.

2.4 Data Extraction and Analysis

Data from each included study were manually extracted. Extracted information concerned the type of adulterant, detection principle, analytical technique or biological system employed, sensitivity, advantages, limitations, and practical applicability. The extracted data were organized, compared, and analyzed to identify common trends, methodological strengths, and existing limitations.

The selected articles were then categorized and thematically analyzed according to their detection approach, including chemical and instrumental methods, biosensor-based systems, and biological or microorganism-based strategies. This enabled the systematic synthesis of findings and allowed for comparisons among various technologies for the detection of adulteration.

2.5 Quality Assessment of Included Studies

In the absence of a formal quantitative quality-scoring system, the methodological quality of included studies was assessed qualitatively. Studies were judged on clarity of experimental design, adequacy of detection methodology, relevance to real food matrices, and consistency of reported results. Articles for which methodologies were clearly described and outcomes reproducible were favored in the analysis.

Since the review is for academic research purposes, no PROSPERO or any other protocol registration platform has been involved. However, an attempt was made to keep the methodology transparent and consistent throughout the review.

3. TAXONOMY AND CLASSIFICATION OF REVIEWED STUDIES

The selected literature was classified into the following categories:

1. Chemical-based detection methods
2. Instrumental and analytical techniques
3. Biosensor-based detection systems
4. Biological and microorganism-based approaches

This classification enabled systematic comparison and thematic analysis of the reviewed studies.

4. THEMATIC ANALYSIS

To systematically synthesize the findings from the selected studies, the literature was analyzed under four major themes. Each theme is supported by a dedicated table summarizing key characteristics, followed by a detailed explanation to aid interpretation.

Based on the thematic synthesis, the reviewed studies were categorized into four major themes:

4.1 Conventional Chemical and Instrumental Methods

4.2 Rapid Biosensor-Based Detection Techniques

4.3 Biological and Microorganism-Based Detection Approaches

4.4 Comparative Summary and Research Gaps

4.1 Conventional Chemical and Instrumental Methods

A substantial portion of the reviewed literature focuses on conventional chemical and instrumental techniques for detecting adulterants in spices and edible oils. These methods form the backbone of regulatory food testing and are widely regarded as reference standards. Chromatographic techniques such as gas chromatography and high-performance liquid chromatography are frequently reported for identifying adulterant oils based on fatty acid composition and triglyceride profiles (Singh et al., 2020; Ali et al., 2019). Spectroscopic approaches, including FTIR and NIR spectroscopy, are highlighted for their ability to rapidly screen samples without extensive preparation.

However, multiple studies emphasize that these methods are associated with high operational costs, require skilled analysts, and depend on sophisticated laboratory infrastructure. Chemical color tests, although simple and economical, are reported to suffer from poor specificity and false-positive results. Furthermore, calorimetric and thermal analysis techniques, while effective in differentiating pure and adulterated oils, involve complex instrumentation and interpretation.

Table 1 indicates a consolidated overview of conventional chemical and instrumental methods discussed across the reviewed studies. The table highlights that although these techniques offer high analytical accuracy, their applicability is largely restricted to centralized laboratories. This limitation significantly reduces their effectiveness for routine surveillance, on-site inspections, and rapid decision-making in food supply chains.

Table 1. Conventional Chemical and Instrumental Methods for Adulterant Detection

Method	principle	Advantage	Limitation
Chemical color test	Visual color reaction	Low cost, simple	Low specificity
Chromatography (GC/HPLC)	Compound separation	High accuracy	Expensive lab-based
FTIR/NIR spectroscopy	Molecular vibration	Rapid, non-destructive	Instrument cost
Calorimetric analysis	Thermal behavior	Reliable	Time-consuming

While a summary of conventional adulterant detection methods is presented in Table 1, it is evident that chromatographic and spectroscopic techniques dominate due to their high analytical accuracy. However, the table also highlights that most of these methods are laboratory-dependent and require costly instrumentation, which limits their suitability for routine field-level monitoring despite their reliability.

4.2 Rapid Biosensor-Based Detection Techniques

Biosensor-based detection methods have gained considerable attention as alternatives to conventional analytical techniques (Rao et al., 2021; Mishra et al., 2023; Patel & Joshi, 2022). These systems integrate a biological recognition element with a physicochemical transducer to produce measurable signals in response to adulterants. Optical, electrochemical, and nanobiosensors are the most frequently reported formats for food adulteration detection.

Table 2 highlights different biosensor platforms used for detecting adulterants in spices and edible oils. The table demonstrates that biosensors offer superior sensitivity and faster response times compared to chemical tests. However, issues such as fabrication complexity, limited shelf life, and the need for specialized materials restrict their large-scale commercialization.

Table 2. Biosensor-Based Detection Methods for Food Adulteration

Biosensor type	Recognition element	Signal type	Advantage	Limitations
Optical biosensor	Enzymes/antibodies	colour/Fluorescence	Rapid, sensitive	Stabilitiy issue
Electrochemical biosensor	Protein/DNA	Current/voltage	High sensitive	Complex fabrication
Nanobiosensor	nanomaterials	Enhanced signal	Ultra-sensitive	High cost

Table 2 indicates that electrochemical and optical biosensors are the most widely reported platforms for detecting adulterants in spices and edible oils. Although these devices demonstrate considerable potential, the table reveals that challenges such as fabrication complexity and dependence on specialized materials continue to restrict their practical deployment.

4.3 Biological and Microorganism-Based Detection Approaches

Biological and microorganism-based detection strategies have emerged as promising alternatives to conventional analytical techniques for identifying adulterants in spices and edible oils (Das & Banerjee, 2019; Chandra et al., 2022). Unlike chromatographic and spectroscopic methods that require sophisticated instrumentation, biological systems rely on measurable physiological, enzymatic, or metabolic responses triggered by specific adulterants (Shah et al., 2020; Yadav & Mishra, 2023). These approaches are particularly attractive for low-cost, field-deployable, and environmentally sustainable screening applications.

Microorganisms can respond to adulterants through mechanisms such as growth inhibition, metabolic disruption, enzyme activity alteration, or visible colorimetric change (Banerjee & Ghosh, 2020). Certain adulterants interfere with microbial respiration, membrane integrity, or nutrient utilization pathways, resulting in detectable biochemical signals (Chandra et al., 2022). These biological responses can be translated into qualitative or semi-quantitative detection formats, including turbidity variation, pH shifts, enzymatic color reactions, and paper-strip assays (Sharma & Kaur, 2021).

One of the major advantages of microorganism-based systems is their minimal infrastructure requirement, which makes them suitable for decentralized monitoring, particularly in resource-limited settings (FAO/WHO, 2018). Additionally, biological detection platforms are generally eco-friendly and compatible with portable sensing formats (Rao et al., 2021). Paper-based biosensors further enhance accessibility by enabling rapid visual detection without the need for advanced laboratory equipment (Sharma & Kaur, 2021).

Despite their promising features, many microorganism-based detection systems remain at the laboratory proof-of-concept stage and lack large-scale validation in real food matrices (Chandra et al., 2022; Yadav & Mishra, 2023). Variability in microbial strains, environmental sensitivity, response time, and reproducibility challenges hinder standardization and regulatory acceptance (Patel & Mehta, 2021). Furthermore, comparative benchmarking against established analytical techniques is necessary to evaluate sensitivity and specificity under practical conditions (Singh et al., 2020).

 ISSN 2394 - 7780

To enhance practical applicability, future research should focus on improving microbial stability, reducing detection time, enhancing specificity toward target adulterants, and integrating these systems into user-friendly paper-based or nanobiosensor platforms (Mishra et al., 2023; Patel & Joshi, 2022). Standardization of protocols and regulatory validation will be essential for the broader adoption of microorganism-based detection technologies in food safety monitoring systems.

Table 3. Summary of Microorganism-Based Detection Systems for Adulterant Identification in Spices and Edible Oils

Biological System	Detection Mechanism	Target Adulterant Type	Advantages	Limitations
Bacterial Growth Inhibition Assay	Reduced microbial growth or metabolic activity	Synthetic dyes, toxic additives	Simple, low cost	Slow response time
Enzyme-Based Microbial Assays	Colorimetric or enzymatic reaction	Chemical adulterants	Visual detection possible	Stability issues
Fermentation-Based Systems	pH change or gas production	Oil blending or impurities	Minimal equipment required	Limited specificity
Paper-Strip Microbial Sensors	Visible color change reaction	Various adulterants	Portable, field-friendly	Requires validation

Table 3 summarizes the key microorganism-based detection systems reported in the literature for identifying adulterants in spices and edible oils. The table highlights the diversity of biological mechanisms employed, including microbial growth inhibition, enzyme-mediated colorimetric reactions, fermentation-induced biochemical changes, and paper-strip sensor responses. Each system operates through a distinct biological pathway, allowing indirect detection of chemical adulterants through measurable physiological or metabolic responses.

The comparative analysis indicates that paper-strip microbial sensors and enzyme-based assays demonstrate strong potential for field-level and preliminary screening due to their portability and visual detection capability. In contrast, growth inhibition and fermentation-based systems, while cost-effective, may require longer response times and exhibit lower specificity. Overall, the table illustrates that although biological approaches offer promising low-cost alternatives, further optimization and validation are required to improve sensitivity, reproducibility, and regulatory acceptance.

4.4 Comparative Summary and Research Gaps

A holistic comparison of all detection strategies is essential to identify research gaps and future opportunities.

Table 4 presents a consolidated comparison across conventional, biosensor-based, and biological methods. The table clearly shows that no single method satisfies all criteria of accuracy, affordability, speed, and field applicability. Conventional techniques dominate regulatory analysis, biosensors offer technological advancement, and biological approaches provide affordability and sustainability. The lack of validated microorganism-based paper-strip systems represents a major research gap that warrants focused investigation.

Table 4. Comparative Summary of Adulteration Detection Approaches

Approach	Cost	sensitivity	Field application	Research status
Chemical/instrumentals	High	Very high	No	Established
Biosensor-based	Medium-High	High	Limited	Emerging
Microorganism-based	Low	Moderate	High	Underexplored

International Journal of Advance and Innovative Research
Volume 13, Issue 1 (XIII): January – March 2026
ISSN 2394 - 7780

The comparative analysis presented in Table 4 shows that conventional and biosensor-based methods generally provide higher sensitivity but are constrained by high equipment costs and limited field applicability. In contrast, microorganism-based techniques exhibit strong potential for on-site use, although further improvements in sensitivity are required.

5. COMPARATIVE ANALYSIS OF DETECTION METHODS

A comparative evaluation of the reviewed detection approaches highlights clear differences in terms of sensitivity, cost, complexity, and applicability. Conventional chemical and instrumental techniques provide high analytical accuracy but are limited by high operational costs, extensive sample preparation, and the requirement for advanced laboratory infrastructure. In contrast, biosensor-based methods offer rapid detection and enhanced sensitivity but often involve complex fabrication processes.

Biological and microorganism-based approaches emerge as promising alternatives due to their eco-friendly nature, low cost, and potential for on-site application. However, their practical implementation, particularly in paper-strip formats, is still in the developmental stage. The comparative insights discussed here are synthesized from the thematic tables presented in Section 4, which collectively highlight trade-offs among accuracy, cost, speed, and field applicability.

6. OPEN CHALLENGES AND RESEARCH GAPS

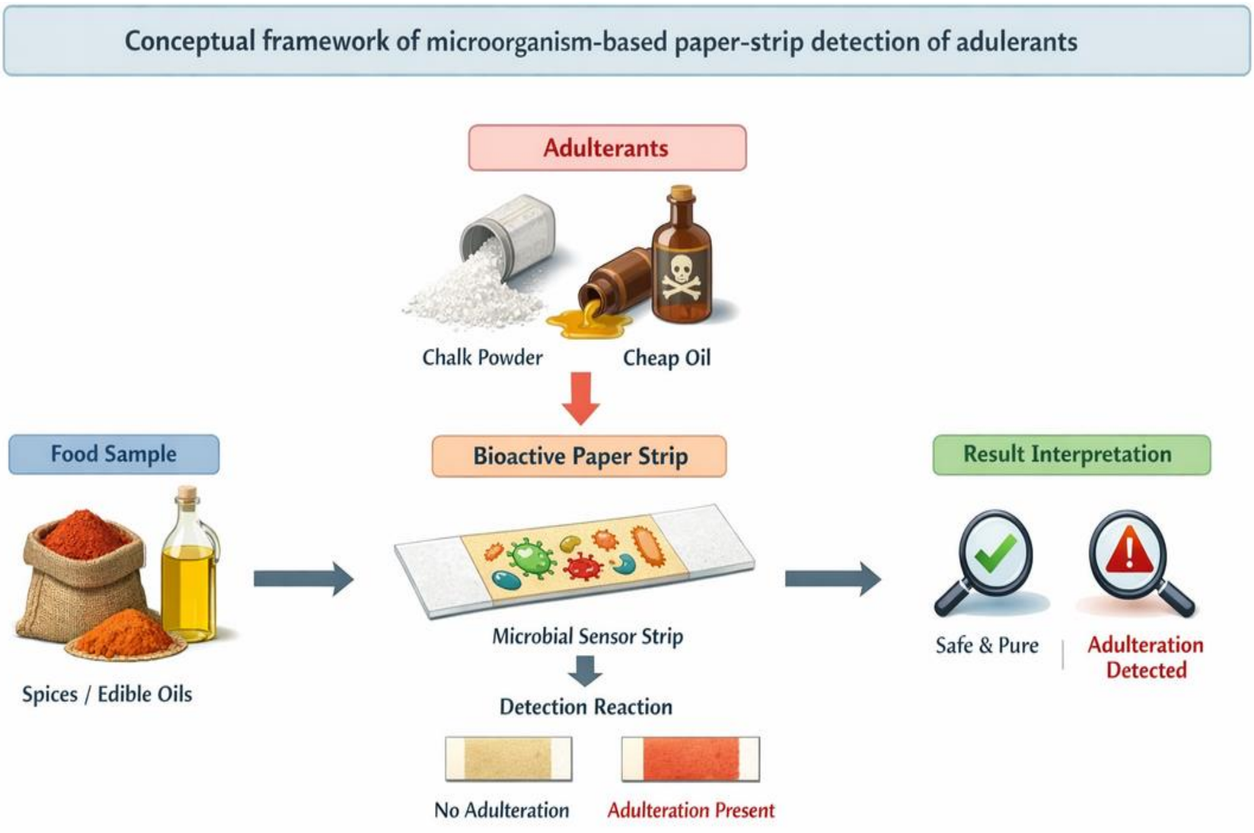
The systematic review reveals several unresolved challenges consistently reported across the literature (Gupta & Bansal, 2021; Yadav & Mishra, 2023)

- Lack of low-cost, field-deployable detection tools.
- Limited studies focusing on microorganism-based paper-strip systems.
- Insufficient integration of biological detection methods for routine screening of spices and edible oils.

These gaps highlight opportunities for future research and innovation.

7. PROPOSED CONCEPTUAL FRAMEWORK

Based on the reviewed literature, a conceptual framework is proposed in which selected microorganisms are immobilized on paper strips to act as biological indicators. Upon exposure to adulterants, observable biological responses such as color change or growth inhibition may provide a rapid and qualitative indication of adulteration. This framework is intended as a future research direction rather than an experimentally validated method.



8. CONCLUSION AND IMPLICATIONS

This systematic literature review demonstrates that while numerous methods exist for detecting adulterants in spices and edible oils, most are unsuitable for rapid, low-cost, and on-site applications. Biological and biosensor-based approaches present promising alternatives, yet microorganism-based paper-strip systems remain insufficiently explored. The findings of this review contribute theoretically by synthesizing existing knowledge and practically by proposing a novel conceptual direction for future research. This work is expected to assist researchers and policymakers in advancing accessible food adulteration detection strategies.

9. FUTURE SCOPE AND LIMITATIONS

The results of the systematic literature review, especially the comparative analysis in Table 4 and the issues raised in Section 6, point out several specific and concrete research directions for the future. While the biological and microorganism-based detection methods have great potential for the development of low-cost and portable adulteration detection devices, their implementation is currently hindered by a number of issues that need to be addressed in the future.

The first issue that needs to be addressed in future research is the standardization of microbial response patterns for particular adulterant-spice and adulterant-oil pairs.

Secondly, more emphasis should be placed on the engineering and optimization of paper substrates to enhance microbial viability, signal stability, and response visibility. Issues such as paper type, moisture content, nutrient supply, and storage conditions should be systematically explored to improve the performance of microorganism-based paper strip tests.

Thirdly, blind validation experiments using actual market samples should be carried out to assess the sensitivity, specificity, and robustness of these biological detection assays. This would enable a direct comparison with existing chemical and biosensor-based detection methods and would help to establish performance standards for these biological assays.

These focused research efforts can facilitate the transition of microorganism-based paper-strip detection assays from laboratory proof-of-concept to practical screening tools.

REFERENCES

1. Kumar, R., Sharma, V., & Gupta, N. (2019). Food adulteration: Issues, challenges, and detection methods. *Journal of Food Safety, 39(2), e12611.*
2. Shah, M. A., Bosco, S. J. D., & Mir, S. A. (2020). Food adulteration and detection strategies: A review. *Food Chemistry, 321, 126681.*
3. FAO/WHO. (2018). *Food safety and adulteration: Global perspectives. World Health Organization*.
4. Ali, J., Tuzen, M., & Citak, D. (2019). Adulteration of edible oils and detection strategies. *Critical Reviews in Food Science and Nutrition, 59(1), 1–16.*
5. Singh, P., Kumar, A., & Singh, R. (2020). Analytical techniques for detection of adulterants in edible oils. *Journal of Food Science and Technology, 57(9), 3173–3185.*
6. Kumar, P., Singh, S., & Yadav, A. (2020). Detection of synthetic dyes in spices: Health implications and analytical approaches. *Food Additives & Contaminants, 37(8), 1345–1358.*
7. Gupta, R., & Bansal, N. (2021). Adulteration of spices: A review of detection methods. *International Journal of Food Properties, 24(1), 1623–1642.*
8. Patel, K., & Mehta, B. (2021). Regulatory monitoring of edible oil adulteration. *Food Control, 123, 107748.*
9. Rao, T. S., Prasad, R., & Kaur, J. (2021). Biosensors in food safety and quality monitoring. *Biosensors, 11(10), 376.*
10. Sharma, D., & Kaur, G. (2021). Paper-based biosensors for food quality monitoring. *Biosensors, 11(6), 185.*
11. Chandra, P., Noh, H. B., & Shim, Y. B. (2022). Microorganism-based sensing strategies for food safety applications. *Biosensors and Bioelectronics, 197, 113763.*
12. Patel, R., & Joshi, M. (2022). Emerging biosensor technologies for food authenticity analysis. *Food Analytical Methods, 15(4), 1021–1035.*

13. Mishra, G., Tripathi, K., & Pandey, S. (2023). Nanobiosensor-based detection of food adulteration: Recent trends and applications. *Sensors and Actuators B: Chemical, 371, 132540.*
14. Yadav, R., & Mishra, P. (2023). Recent advances in rapid detection of food adulterants. *Foods, 12(18), 3373.*
15. Das, D., & Banerjee, R. (2019). Biological indicators in food quality assessment. *Journal of Biological Methods, 6(4), e120.*
16. Banerjee, S., & Ghosh, M. (2020). Microbial assays for rapid food safety assessment. *Journal of Microbiological Methods, 176, 106006.*