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Detection Methods for Contaminated Food

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Abstract: ***Food contamination is the term used to describe the presence of undesired and hazardous chemicals on food items that can result in foodborne disease. Food deterioration and the ensuing foodborne illness can be caused by physical, chemical, biological, or environmental pollutants. The public's health is now seriously threatened by food contamination. Statistical measurements in the last few decades have produced many negative results. Food contamination causes 420, 000 deaths and 600 million illnesses globally each year. Food safety ensures that consumers are protected from foodborne illnesses. The food may be impacted by a number of significant factors, including microbiological, chemical, nutritional, and natural variations, water flow, climate changes, and natural cleanliness. Food spoils as a result of contaminants that enter throughout the processes of preparation, storage, preservation, and transportation. The pollutants can be found using a variety of techniques, such as molecular biology - based, immunological, and culture - based techniques. These techniques are quick, extremely sensitive, precise, and economical. For the long - term detection or identification of foodborne pathogens, this review offers a thorough overview of food contaminants and their detection methodologies, including both traditional and cutting - edge approaches.***

Keywords: Food contamination, Biological contamination, Chemical contamination, Physical contamination, Biosensor, Immunological methods

1. Introduction

Since ancient times, the science of food has been well recognized. Since the Stone Age, it has been clear that food has been essential to human civilization. Since food is vital to our existence, it is important to comprehend the science underlying food contamination [1]. The existence of undesirable and hazardous substances in food is referred to as food contamination. Contaminated food can be a long - term health risk if it is not discovered [2]. Food contamination can occur in two different ways. They may be added during the food production, processing, or storage processes, or they may be naturally present in the food item [3]. The four most important types of food pollutants are as follows - they are allergic, chemical, physical, and biological. When dangerous germs are found in food, biological contamination happens [4]. Bacteria, molds, yeasts, viruses, and parasites are among the dangerous microorganisms that can cause deadly diseases. Shigella, Salmonella, Escherichia coli, Norovirus, and Hepatitis A are a few examples of biological contaminants [5]. Chemical contaminations happen when undesirable compounds are present in food. Cleaning solutions, pesticides, fertilizer residues, industrial oil, and additives are a few examples of dangerous chemical contaminants that can cause burning, swelling, stomach problems, and long - term effects. Toxic heavy metals, industrial, agricultural, and natural sources are the several categories of chemical contamination. When undesirable foreign substances are present in a food product, physical contamination takes place [6]. While glass, plastic, soil or sand, and metal shards are regarded as unnatural, other dangerous physical contaminants—like hair feathers, raw fruit skin, bone fragments, and insect droppings—are seen as natural. Broken teeth, choking, bleeding, and severe traumas are all brought on by the physical pollution. Maintaining hygiene, keeping raw and cooked food separate, managing temperature, and using clean, fresh water when cooking are some essential steps in preventing food contamination [7]. The bacterial toxins and their pathogens can lead to such diseases as diarrhea and spread from person to person. These pathogens are causing more and more outbreaks of disease every year [8]. Salmonella species, E. coli, Shigella species, Yersinia species, Listeria monocytogenes, Staphylococcus aureus, Clostridium species, Mycotoxins, Alfatoxin, Ochratoxin A, Citrinin, Patulin [9], Giardia, Cryptosporidium, Vibrio cholerae, Campylobacter species, Vibrio vulnificus, Legionella, Naegleria fowleri, Listeria monocytogenes, Aspergillus flavus, Xero philic penicillia, Xerophilic aspergilli, Eurotium halophilicum, Xeromyces bisporus, Chrysosporium, Eurotium, and Rhizopus was identified as harmful pathogens that causes hazardous illnesses [10] [11].

Traditional techniques, such as those based on culture, biochemical testing, immunology, nucleic acid analysis, and more sophisticated techniques like spectroscopy and biosensors, are associated with the identification of food pollutants. A major contributing element to many diseases worldwide is food contamination. It has a serious negative impact on human health and frequently results in death. Unfavorable health effects may become a sad reality if food contamination is not detected and addressed promptly [12]. Food contamination poses a serious risk to human health and is a major issue for the industry's food safety and quality control. Food contamination has a major effect on the health sector in addition to the food manufacturing and distribution industries [13]. The main contamination source is from the agricultural fields during different stages of harvesting including preharvest, harvest and postharvest. Human being, whether they are producers or consumers, are aware of the different ways through which contaminant such as mycotoxins may enter the food, the main critical stages of food chain involving in contamination and the basic control tips in the field [14]. The surveillance of food borne illness is challenging and the following aspects make it hard to do. On the other hand, foodborne diseases may be very severe, and in the bad case scenario, they can even lead to death. Food - borne illnesses and diseases pose a great risk to the health and life of people as over 200 foodborne diseases have been identified [15]. A passage to these pollutants is associated with a variety of severe problems with health like endocrine disruption, reproductive problems, cancer, cardiovascular disease, obesity and diabetes [16].

The majority of the foodborne diseases are characterized by the more intense or lengthier form, and are normally restricted to short bouts of diarrhea, nausea or other acute gastrointestinal system. Several other diseases can be caused by the consumption of foods contaminated by microbial pathogens and it may cause fever, vomiting, weakness, chills and aches, headaches, abdominal pain, constipation, sore mouth, blurred vision and muscle paralysis [17].

The contaminants in food that can cause foodborne illnesses are bacteria. The gastrointestinal tract is the path by which the pathogens get into human body and bring about many foodborne diseases. The foodborne pathogens can get into the body through contaminated water or through undercooked and contaminated food. The first outbreak of E. coli O157: H7 in China was reported in the year 1986. Humans, livestock and other animals from the Fujian, Gansu, Zhejiang, and Anhui provinces have all been successfully isolated with E. coli O157: H7 and it is one of the prior pathogens that are responsible for outbreak of foodborne [18]. Cultures followed by standard biochemical tests are still best way to diagnose E. coli infections especially during outbreaks since the potential need to compare the results with other typing methods may arise [19]. The health repercussion of these foodborne infections is becoming more severe due to the increased growing rate of antimicrobial resistance in these foodborne pathogens, a problem that has been recognized for >3 decade [20].

According to the Centre for Disease Control and Prevention, it is estimated that such hidden and unknown pathogens cause as much as 81% of the foodborne illness cases in the United States [21]. They also estimated that foodborne diseases cause roughly 76 million cases of illness, out of which 3, 25, 000 hospitalizations and 5000 deaths occur in the United States each year. The Centre for Food Safety and Applied Nutrition (CFSAN) within the United States Food and Drug Administration (FDA) along with the Food Safety and Inspection service (FSIS) and Centers for Disease Control and Prevention (CDC) have released a research study regarding the impact to public health caused by the intake of specific types of ready - to - eats food that can be contaminated with the foodborne pathogens [22].

The exposure of human to toxic cyanobacteria and their toxins comes in the form of various health problems, some of them being not quite serious but others being life - threatening [23]. The dramatic rise in the population of the world means that food production has to rise in parallel as well. Human consume a lot of food that is highly appreciated socially, and food that is also nutritious and very desirable due to its high quality, therefore the issue of food contamination should be avoided to make food stay in the high position. The impact of the disease on mankind is large because of the rich nutritional contents as well as the production that make the food susceptible to contamination by pathogenic microbes which could cause diseases in humans [24]. Public health agencies, regulatory agencies and the food industry, as well as consumers, have to keep on with the efforts to ensure the food quality despite the places where it is grown, processed, served and eaten [25]. Globalization of food products, expansion in the food business and change in eating habits are the factors affecting food safety, in terms of hazards and threats. The increase in foodborne pathogens that are resistant to antimicrobial drugs is a common health problem around the world that is a contributor to this risk [26]. There are multiple different aspects are affecting the frequency of foodborne illnesses. Some of them are the demographic factors like the quick population explosion, a shift toward an aging population, higher numbers of immunologically compromised individuals around the world, people going cross - country more often, as well as changing eating habits demand for natural and minimally processed foods or groceries [27]. Food companies have always been keeping under their control the end product so that the food leaving the factory does not be loaded with more than the required number of non - pathogenic and pathogenic microbes [28].

In a number of publications, reports, and papers, the World Health Organization (WHO) acknowledged food contamination as a worldwide issue. The World Health Organization (WHO) promotes food safety and awareness initiatives by offering guidelines that consumers and food handlers should be aware of. In order to guarantee food safety and uphold health security, there are five crucial components [29].

2. Materials and Methods

The electronic search was conducted using Google Scholar concerning various materials, methods (conventional and traditional) and technologies which is used to detect food contaminants. The main keyword ‘food contamination’, ‘biological contaminants’, ‘chemical contaminants’, ‘physical contaminants’ and ‘human health’ was crossed as well as their clinical and forensic signs. Furthermore, retrieved journal articles, books were reviewed to expand the source of information.

3. Contamination detection techniques

In recent years, many people have had foodborne illnesses brought on by food tainted with bacteria, viruses, fungus, parasites, or toxins. Symptoms of foodborne sickness include fever, nausea, vomiting, diarrhea, and cramping or discomfort in the stomach. The primary factors influencing food contamination detection methods are size, cost, specificity, sensitivity, and accuracy. Food pollutants can be easily identified and analyzed thanks to the detection method. A range of techniques are included in the two categories of detection methods, conventional and advanced [30].

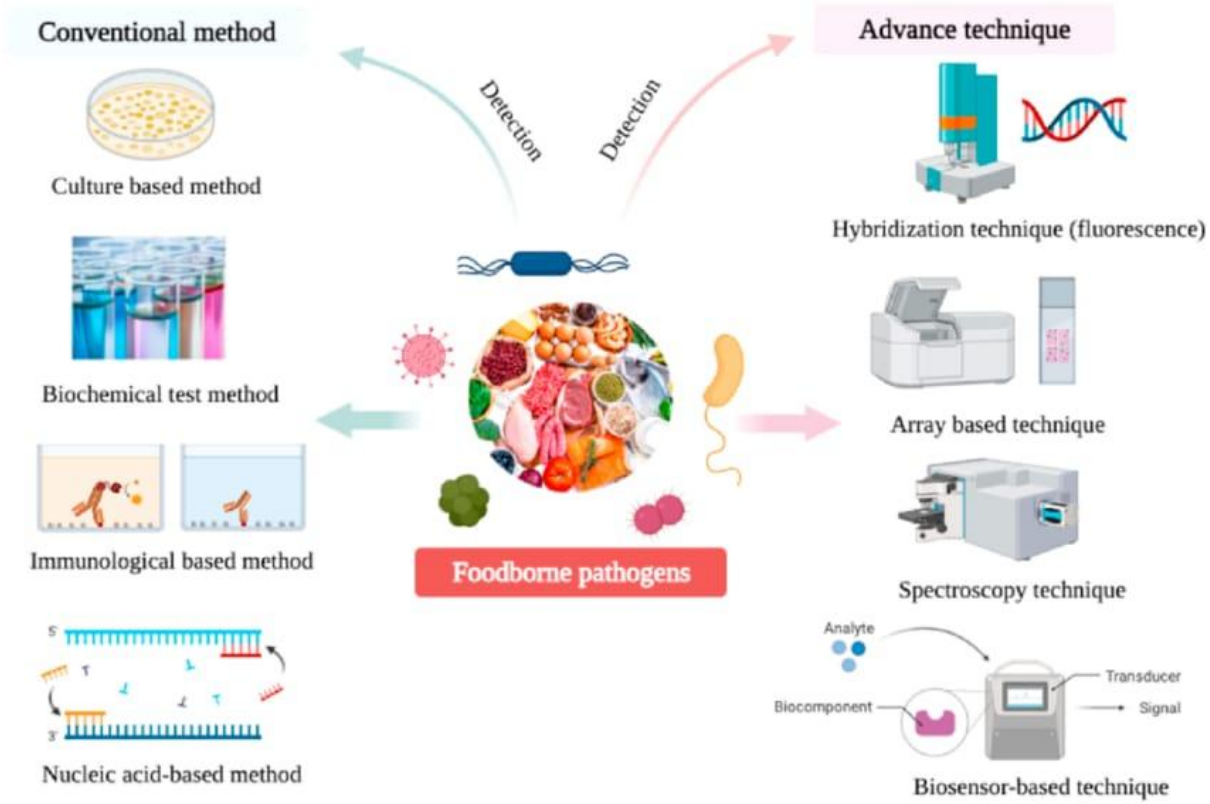

Figure 1: Different types of Conventional and Advanced method https: //pmc. ncbi. nlm. nih. gov/articles/PMC10161726/#: ~: text=The%20identification%20of%20foodborne%20pathogens%20is%20associated%20with, %28e. g. %2C%20hybridization - based%2C%20array - based%2C%20spectroscopy - based%2C%20and%20biosensor - based%20process%29%20techniques.

3.1 Conventional methods

One common technique for detecting contaminants is the conventional approach. Despite being a time - consuming and economical approach, it has multiple uses, including culture and isolation, morphological study, biochemical activity detection, and serological testing. This technique is mostly used in food analysis to determine the exact quantity of microorganisms present and to identify pollutants [31].

3.1.1 Culture - based method

The earliest detection technique is the culture medium - based method. Isolating bacteria in pure culture or a particular target organism, indicating their characteristics, obtaining sufficient growth for testing, assessing antibiotic susceptibility, and maintaining stock cultures are its goals. The bacterial groups can be cultured using the suitable culture media and these bacterial groups are responsible for foodborne illnesses through the direct growth of the bacteria themselves and secretion of toxin [32]. Bacteriological culture media can be in the form of liquid (broth), solid (such as plates or slants), or semi - solid (such as deeps). Both solid and semi - solid media contain materials that make them firm, such as agar or gelatin. Agar is the most common one since it is a product of red algae, inert, and not nourishing, which makes it very suitable for forming a solid surface. It would promote the growth of bacteria colonies on such a surface. Colony is a visible aggregation of bacterial cells [33]. This technique, which makes use of a particular media, is carried out in microbiological laboratories. In addition to being quick, sensitive, selective, and easy to use, the culture medium - based approach has certain drawbacks, including being labor - intensive and time - consuming [34]. The various forms of culture procedures include liquid culture, pour plate culture, stab culture, lawn culture, streak culture, and stroke culture [35].

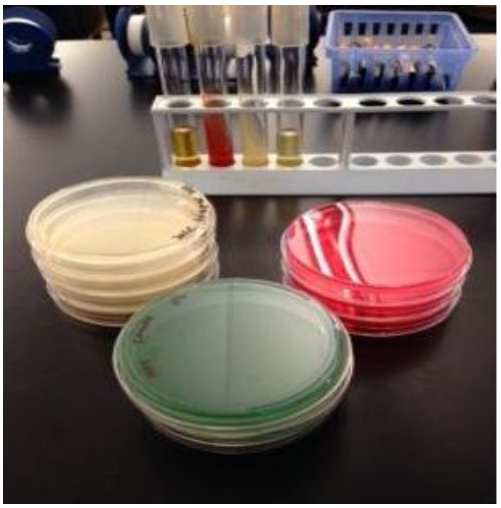

Figure 2: Different type of culture https: //bio. libretexts. org/Under_Construction/Purgatory/Microbiology%3A_A_Laboratory_Experience_ (Lumen) /02%3A_Main_Body/02.3%3A_Bacteriological_Culture_Methods

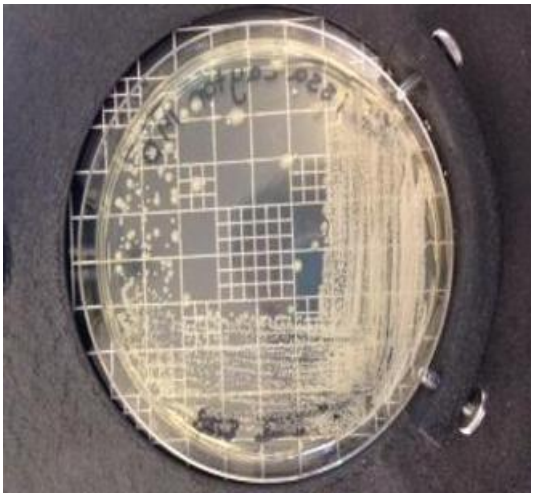

Figure 3: Colonies on an agar plate

3.1.2 Biochemical test - based method

The biochemical test method uses the metabolic rate of the microorganisms to identify their types. The biochemical test's main goals are to guarantee or improve the accuracy of identifying an unknown sample, speed up the identification of microorganisms, and lower costs. It is also the trend in microbial identification that is developing the quickest [36]. Many of the metabolic processes involved in these operations are naturally triggered by the microorganism's presence. The most precise identification of the bacterial species produced by them is made possible by the biochemical assays we have created to measure the quantities of bacterial enzymes [37]. In order to do biochemical analyses, we inject a bacterial culture into a medium that contains a certain substrate. We then watch to see how the media changes, indicating the presence of a particular enzyme or metabolic pathway [38].

Figure 4: Biochemical analysis and chemical analysis in lab *https: //www.dreamstime. com/biochemical - analysis - chemical - analysis - lab - background - biochemical - analysis - chemical - analysis - lab - n - image134289179*

3.1.3 Immunologically based technique

To identify foodborne pathogens, the immunologically based method depends on the particular binding between an antigen and an antibody. This technique depends on the counteracting agent's epitope location, which binds to the particular antigen. Sensitivity and specificity are crucial metrics for assessing the effectiveness of unique testing, such as immunological techniques [39]. Numerous extremely sensitive and particular samples can be prepared thanks to the simple, labor - efficient, and efficient technique [3]. There are, however, certain drawbacks, including the possibility of false positives and insufficient microbiological coverage [40]. Some immunological techniques include the gold - labeled immunosorbent assay (GLISA), immunomagnetic separation, lateral flow immunoassay, immunofluorescence test, immunodiffusion assays, and enzyme - linked immunosorbent assay (ELISA). To carry out the development, optimization and validation of an immunoassay in first place, it is mandatory to clarify the relevant immunoassay parameters [41]. Over the last couple of years, the development of detection experiment system for measurement of the antigens by the use of immunoassay techniques has been notably successful according to a series of increasingly reliable studies [42].

3.1.3.1. Enzyme - linked immunosorbent assay (ELISA)

ELISA is a method of immunology, which identify the antigen - antibody complex using an enzyme to track changes in sensitivity in the sample. The antigen is stuck to a microplate well either by putting it there directly or by using the specific antibody that is named as the 'capture antibody'. In each step, the well is washed away using a buffer solution. The substrate addition produces a colored signal, which tells about the presence of the antigen in the sample [43]. The enzymes used in ELISA may differ, but the general ones are alkaline phosphatase, horseradish peroxidase (HRP) and beta galactosidase. Peroxidase enzyme, which actually can catalyze reactions with several substrate systems that give coloured products that are detectable by the naked eye. Almost every time, the utilized proton receptor precipitates after the reaction, thus rendering the assay less sensitive. The activity of peroxidase is inhibited by bacteriostatic agents like sodium azide thus decreasing its shelf life. Alkaline phosphatase enzyme is very sensitive to sodium azide and stable [44].

3.1.3.1.1 Direct ELISA

Direct ELISA is an analytical method to which the isolated and purified illustrative (analyte) link to a solid surface well and thus attacked enzyme - labeled polyclonal antibodies in the assay and detect the antigen. In following procedure, the buffered solution contains the analyte that is added to 96 microtitre wells are coated with antibody and allowed to incubate overnight (16 h, 4 Degree Celsius). Plates were washed three times with washing buffer and 100L of standard were added and then 100L of tracer in PBS with 0.5% BSA were applied to each single well. The plate were again incubated at (1 h, 4 Degree Celsius) and washing the step again and again and substrate solution was added after 15 min the enzymatic reaction was stopped by adding stopping reagent.

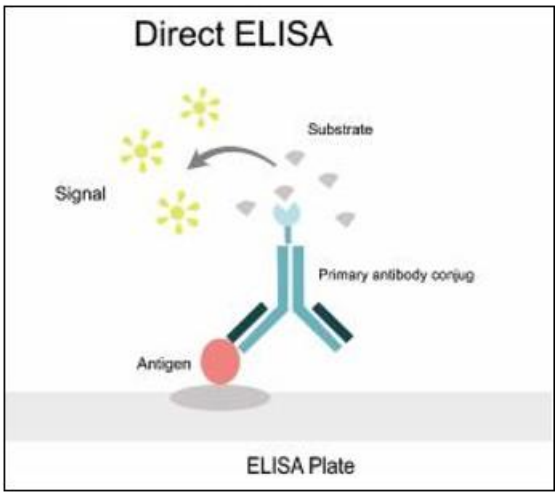

Figure 5: Direct ELISA
https: //www.creative - diagnostics. com/ivd - materials/introduction - to - direct - elisa. html

3.1.3.1.2 Indirect ELISA

It is similar to the direct ELISA, the plate is incubated and washed, then a substrate is added and a microplate reader is used to scan the wells. The primary antibody is introduced and then sets out link with the antigen and is connected with the plate by means of the carbonate - bicarbonate plaque buffer. The secondary antibody can be tagged with a fluorophore, and the findings can be checked under the ultraviolet light using a fluorometer which result is quantified.

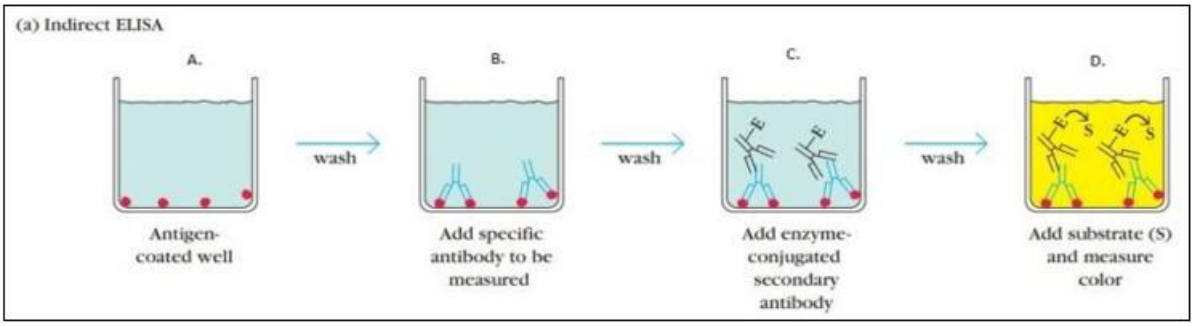

Figure 6: Indirect ELISA
https: //microbiologynotes. org/elisa - principle - types - uses - advantages - and - disadvantages/

3.1.3.1.3 Competitive ELISA

It serves as an invaluable instrument to decipher food pathogens since the method is low on cost, high speed, clear to readout and highly selective. The competitive enzyme - linked immunosorbent assay is reliant on three main entities that is antibody that attaches itself to an antigen of interest. A competing antigen that opposed for the binding with certain antibody and signal transducer element that reads the signal output.

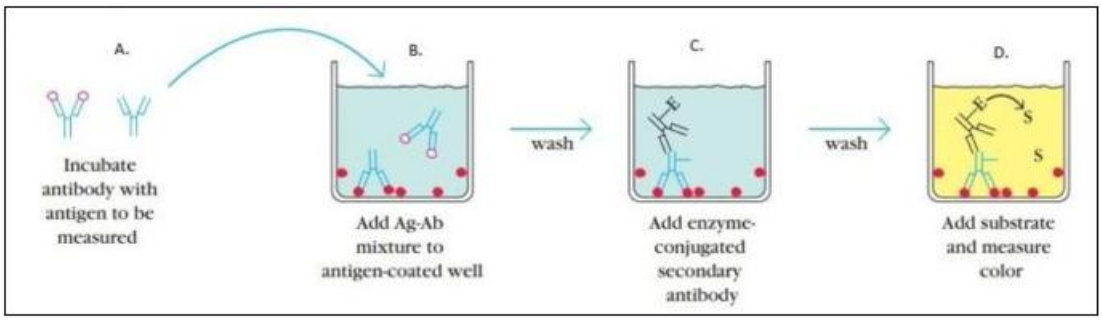

Figure 7: Competitive ELISA
https: //microbiologynotes. org/elisa - principle - types - uses - advantages - and - disadvantages/

3.1.3.1.4 Sandwich ELISA

This method utilizes two antibodies for one antigen and is used to bind to the target molecule while the secondary antibody and the enzyme specify the target molecule, forming a sandwich, like in a primary antibody, the target molecule and the secondary antibody complex. The development of a color with the enzyme - substrate mixture confirms the presence of microbes in the food sample [45 - 47].

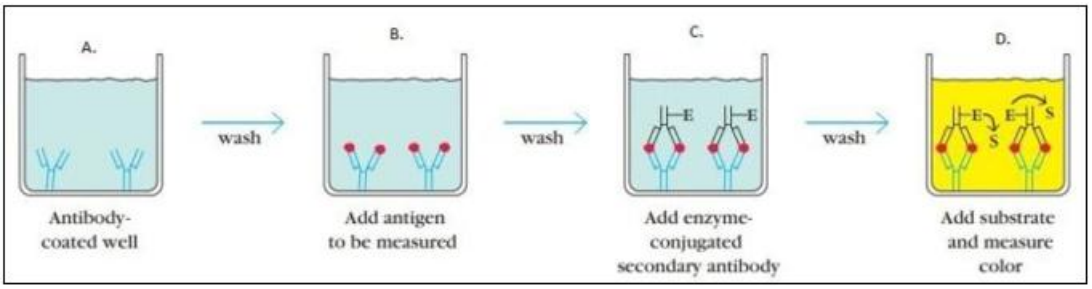

Figure 8: Sandwich ELISA
https: //microbiologynotes. org/elisa - principle - types - uses - advantages - and - disadvantages/

3.1.4 Nucleic acid - based technique

Nucleic acid - based techniques recognize DNA or RNA groups that have been isolated from the microbe and are used as detection techniques. Techniques based on nucleic acids can examine the microorganism and produce data quickly since they are very sensitive and specific [48]. There is now proof of the method's recognition. Without having to wait for the delivery of generic, perhaps unattractive medication, the patient can receive targeted antimicrobial therapy immediately thanks to this quick distinguish evidence [49]. It is not for the only working of the detection method but also because food particles interfere with the technique, and it is also impossible for to differentiate the DNA from live cells or dead cells. The difficulties in the nucleic acid based method are as follows: purification, cell lysis, nucleic acid extraction, failed reaction, cross - contamination, non - target cell DNA competing and false positive signal can be solved only through the development of the nucleic acid - based method. The key issue is to create a primer that amplifies only the non - target sequence [50]. Clostridium botulinum, Vibrio cholerae, Staphylococcus aureus and Escherichia coli O157 that produces toxic bacterial pathogens and responsible for foodborne diseases [51]. There are different form of nucleic acid amplification - based methods, i. e., polymerase chain reaction (PCR), nested PCR, real - time PCR, quantitative real - time PCR, reverse transcriptase PCR (RT - PCR), real - time reverse transcription PCR (RTI - RT - PCR), and multiplex PCR [52]. Nucleic acids (bacterial or viral) derived from microbes can enter the food chain and their reservoirs may be the same as for the pathogens [53]. As the need for diagnosis and the development of nucleic acid amplification techniques increases, the low cost, easy to operate and rapid detection methods become more and more concern [54].

3.1.4.1 Polymerase Chain Reaction

Polymerase chain reaction is a technique based on amplifying specific DNA segments, which are then separated and detected. Polymerase chain reaction (PCR) method can be used to diagnose a wide range of fungi such as Staphylococcus aureus, Listeria monocytogenes, Salmonella spp., Bacillus cereus, Campylobacter jejuni [55]. There are quite a few formats that can be used for performing PCR, for example, Real time PCR where the DNA is being amplified while the reaction is being monitored, Multiplex PCR which is the one that is done when more than one primer pair is used for the simultaneous" detection of more than one type of bacteria [56]

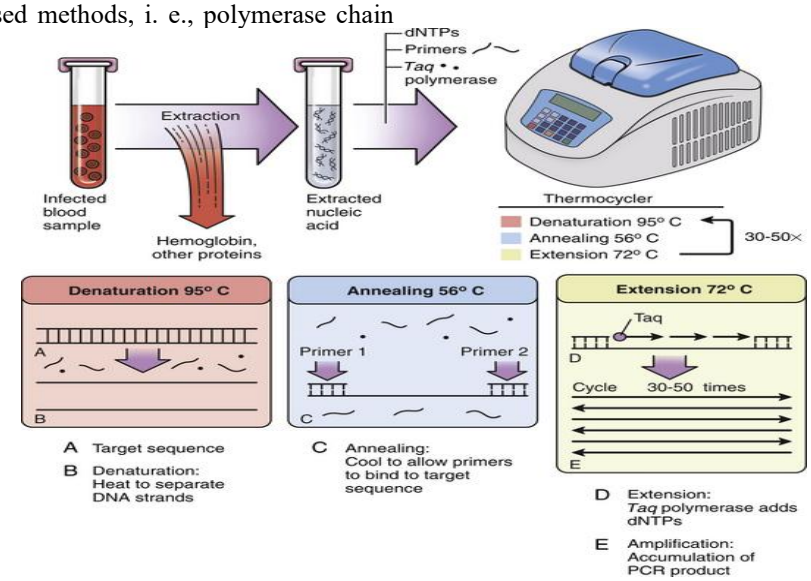

Figure 9

Figure 9: *Basic PCR assay. Nucleic acid is extracted from a clinical specimen through removal of contaminating proteins such as hemoglobin. Two primers are added that hybridize at each end of a specific segment of a pathogen's DNA. Also present in the reaction mixture are the enzyme Taq polymerase (dots) and free nucleotides (dNTPs) for new DNA. A thermocycler is used to rapidly and repeatedly heat and cool the tubes through denaturation, annealing, and extension steps. Denaturation separates double - stranded DNA. Annealing occurs at a specific temperature that causes the primers to bind only to their target sequences. When the reaction mixture is then heated to 72°C, the Taq enzyme uses the primers as initiation points for DNA extension, and the target sequence is copied. The process is repeated 30 to 50 times, with logarithmic accumulation of the PCR*

product, so there are millions of copies of the target pathogen's DNA. These can then be detected using agarose gel electrophoresis
https: //veteriankey. com/nucleic - acid - detection - assays/

3.2 Advanced approach

By examining, categorizing, and recognizing different kinds of food products, the advanced method uses new technologies to identify food pollutants. Because of its quick identification and excellent outcomes, the sophisticated approach is the most popular and extremely sensitive. Now a days, advanced techniques is the most common used for the contaminant detection such as UV - Visible spectroscopy, Immunoassays, Raman spectroscopy, Hybridization technique, Biosensor method, while most of these techniques set up justifiable detection limit for different food contaminants, there are still things left to be done in the field of sensing in the complex food matrixes, multiplex sensing of contaminants and the retainment to measure in the field environment and proper resources are still challenge to be solved [57].

3.2.1 Hybridization Method

To identify a collection of microorganisms and their species, we employ the hybridization method. Molecular genetic identification is the foundation of this technique, which is quick, reliable, and extremely sensitive [58]. Techniques that use hybridization chain reaction as a signal amplification tool have become popular in pathogen detection [59]. This method has been the backbone for the straightforward production of two hairpins. In a cascade reaction, it leads to the formation of long - nicked duplex DNA with the probes. These hairpin probes are modified to produce signals. At the same time, they are connected with the hybridized product to show the presence of pathogens [60].

Fe_0O_4 magnetic beads with two DNA hairpin probes tagged with carboxyfluorescein (FAM), such as H1 - FAM and H2 - FAM, are used to detect Salmonella spp. We observed as little as $6.9x10^2$ CFU/g when we placed these on spiked lettuce [61]. Hybridization methods have been presented as a mean of determining the presence of entero viruses, rotaviruses, enteric adenoviruses and paroviruses. The analysis of foods for the presence of these viruses by hybridization method is still developing [62].

3.2.2 Spectroscopy Technique

Spectroscopy is a scientific field that investigates matter and electromagnetic radiation. This method is among the most effective ones for studying atomic and molecular structure [63]. These spectra allow us to find, recognize, and measure details about atoms and molecules. Atomic spectroscopy, infrared spectroscopy, visible spectroscopy, Raman spectroscopy, and nuclear magnetic resonance are the most widely utilized techniques [64].

3.2.2.1 Raman spectroscopy

In raman spectroscopy, the use of scattered light to gain knowledge of the molecular vibration that give the details about structure, symmetry, electronic environment, and bonding of the molecule and it enables the qualitative and quantitative analysis of the individual compounds [65]. This method holds the qualities of high sensitivity and accuracy, they are usually time - consuming and needlessly expensive [66].

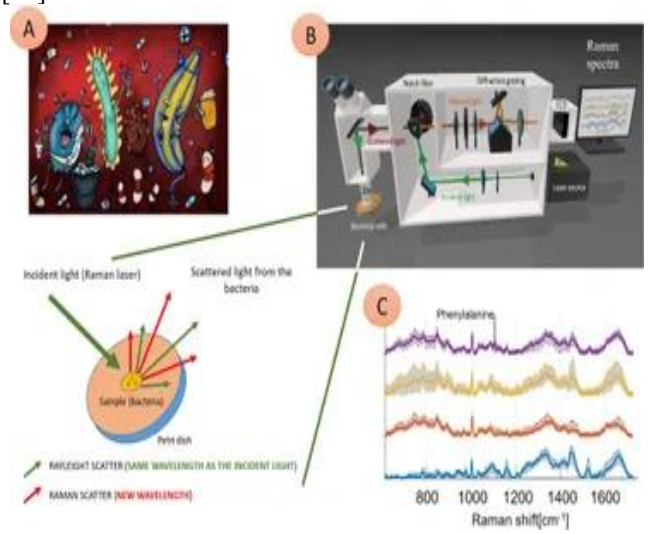

Figure 10: *Illustration of four different microbial species interacting with the immune system and their Raman spectra. (**A**) Microbes are present in the human body, causing an infection. These pathogens can be identified using Raman spectroscopy technique (**B**) —here: probing laser (green) is focused on the sample (bacteria), and a small amount of light, which transports the chemical structure of analyzed bacteria, is reflected (red) and in the next step further analyzed. Consequently, four Raman spectra (**C**) show information about molecular bond vibrations of given bacteria, such as phenylalanine at 1005 cm^{-1}. In this example, the naked eye can see differences between the spectra of four samples. Thus, these pathogens can be identified quickly (in minutes) to treat infection with tailored antibiotics. (**C**) Examples of Raman spectra: Staphylococcus pasteuri (violet curve), Staphylococcus warneri (yellow curve), Streptococcus oralis (red curve), Staphylococcus sciuri (blue trace).*
https: //www.frontiersin. org/journals/cellular - and - infection - microbiology/articles/10.3389/fcimb.2022.866463/full

3.2.2.2 Fourier Transform Infrared Spectroscopy (FTIR)

Fourier Transform Infrared Spectroscopy has placed itself as one of the primary analytical methodologies and has been possible to be connected with other analytical methods, leading to better research opportunities and new more application. FTIR spectroscopy is a science that began with the invention of the interferometer by Michelson (1891, 1892). He had used the interferometer to measure the precise wavelength of light and he also made the interferometer to have a collection of interferograms. FTIR instruments now have new features like easy to use, fast, extreme sensitivity and a lots of samples can be processed. One of the disadvantages of FTIR is that it is unable to detect atoms and monoatomic ions, as well as inert gases such as helium and argon [67].

Figure 11: Fourier Transformed Infrared Spectroscopy (FTIR)
https: //www.unh. edu/research/fourier - transform - infrared - spectrometer - ft - ir

3.2.2.3 Nuclear Magnetic Resonance Spectroscopy (NMR)
Nuclear magnetic resonance spectroscopy is denoted by term physicochemical analysis technology can be utilized as a method for research of the nature of matter using the interaction of the radio - frequency radiation with atomic nuclei. Through the interaction of the radio - frequency radiation regard to the energy gradient, a state change to the particular property of the atomic nuclei is brought about and this property is known as nuclear spin [68]. A logical extension of these principles would be the introduction of further NMR dimensions that are based on molecular features like size, shape, mass and charge [69].

Figure 12: *The **400 MHz NMR** is equipped to collect data on **liquid and solid samples** using almost any NMR - active nuclei. https: //chemistry. cas. lehigh. edu/facilities - menu/content/nmr - spectroscopy*

3.2.3 Array - Based Method
The microarray is composed of an ordered set of probes that include nucleic acids, nucleic acid analogs including peptide nucleic acids (PNA), locked nucleic acids (LNA), proteins, carbohydrates, tissues, cells, and polymers. The significance of this technology is in extremely parallel measurement with the benefits of high throughput, compactness, and fast speed, as most arrays today have hundreds to thousands of probes available. As a result, microarray technology has seen significant advancements in drug resistance, pharmacogenomics, medical research, and molecular diagnosis [70].

3.2.4 Method Based on Biosensors
Electronic devices known as biosensors collect biological data and convert it into electrical impulses. Its core tools are the bio - receptor, transducer, analyte, and display, which are the main components of any biosensor. An analytical tool that can communicate or identify the presence of the analyte in the medium is an example of a biosensor [71]. The measurements are usually taken using a transducer, and then the data is processed. Because they choose to employ the optical measurement technique, optical biosensors differ from other types of sensors [72].

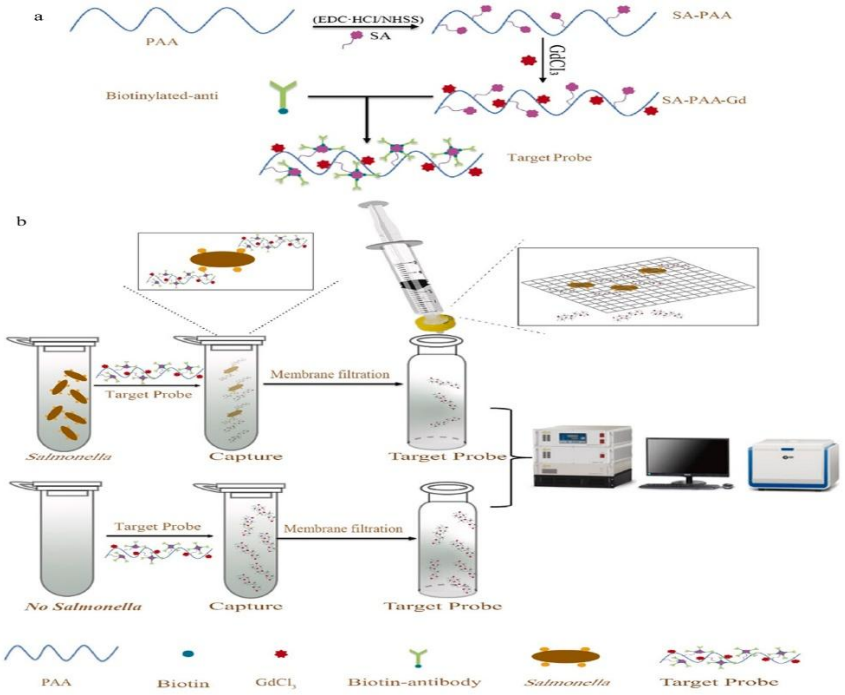

Figure 13: ***Schematic diagram of NMR biosensor to detect salmonella in milk. Firstly, the target probe was prepared (a) followed with detection of salmonella in milk (b).***
https: //www.tandfonline. com/doi/full/10.1080/21655979.2024.2310908#d1e789

3.2.4.1 Electrochemical Biosensors

The concept of rapid foodborne pathogen detection is made feasible by the newly developed technique of electrochemical biosensing that is applicable for the analysis of foodborne pathogens in a short period of time and has a high degree of sensitivity and selectivity as comparable to the traditional methods. The electrochemical biosensor's key component, the bio - recognition element was affixed on the surface of the electrode by physical or chemical method. This methodology can alternatively read the corresponding target molecule and get it capture onto the electrode surface, due to the specific recognition force between bio - recognition element and the substance to be tested. The electrode is actually the centre of the sensor and it can translate the identification signal that was originally generated in the surface of the electrode and change it into electric signal, such as current, voltage and resistance which are easy to measured and examined the analysis [73].

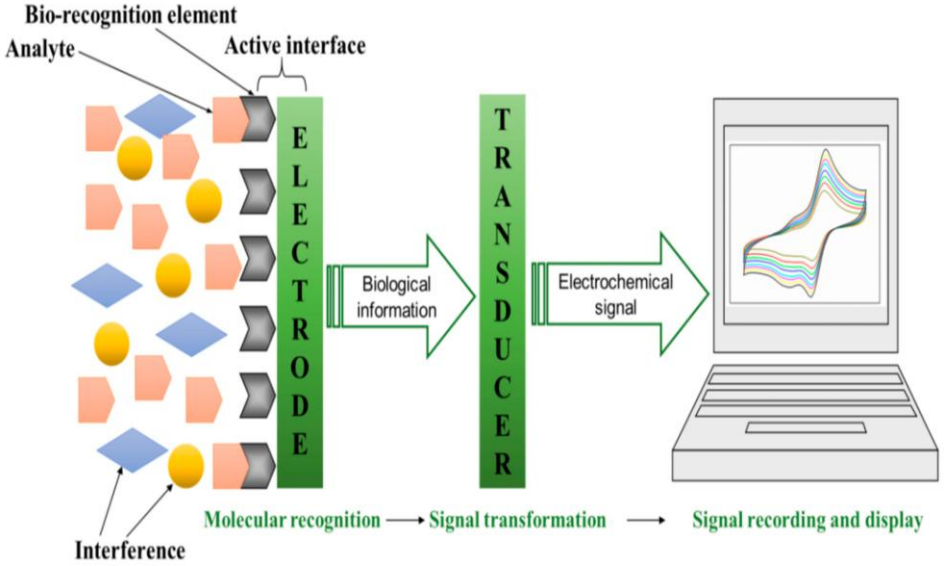

Figure 14: *A schematic representation of the electrochemical biosensor. After the analyte contacts a recognition element on the surface of the biosensor, physical or chemical changes yield a reaction that is transformed into electrochemical signal. This information can be further processed to derive the pathogen to determine the concentration of the pathogen and changes in the composition of the analyte.*
https: //www.mdpi. com/2072 - 666X/10/4/222

3.2.4.2 Optical Biosensors

Optical detection is a procedure that is made possible by the interaction of the optical field with a biorecognition element. Optical biosensors consist of mainly two general modes: label - free and label - based. To put it briefly, the interaction between the transducer and the analyzed substance directly

produces the measured signal in a label - free mode. The utilization of a label in sensor technology is a characteristic of label - based sensing. Optical biosensors utilize strategies like colorimetry and fluorescence to screen the movement of organisms in genuine time. The main goal of optical biosensor is to manufacture a signal that is proportional to the concentration of a given substance (analyte) [74].

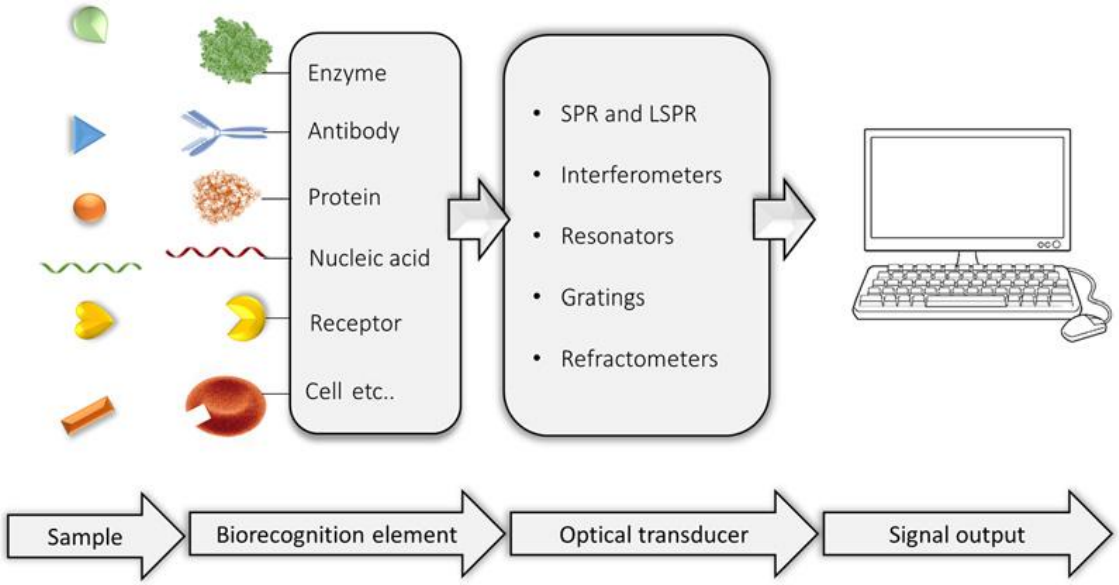

Figure 15: Optical Biosensor
https: //www.researchgate. net/figure/Optical - biosensors_fig1_304624531

3.2.4.3 Bioluminescence - Based Biosensors
These biosensors degree ATP, which is a biomarker for microbial life. The bioluminescence response radiates light corresponding to the sum of ATP. This measures defilement viably and quickly. The speed and efficiency are the main strengths, biosensors are not like traditional microbiological methods which may last for days, but the biosensors have capacity to deliver the results in minutes to hours right on the site. On - site testing numerous biosensors are convenient, permitting for testing promptly on - site in different situations to upgrade nourishment security observing over the supply chain. Due high affectability and specificity, they can identify miniature levels of contaminants, which ensures indeed minor defilement is rapidly recognize [75 - 79].

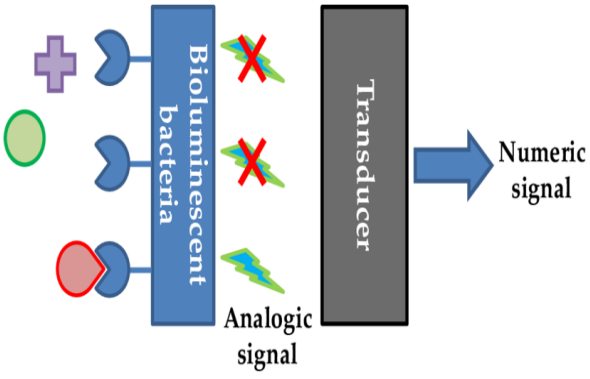

Figure 16: Principle of a bacterial bioluminescent biosensor
https: //www.researchgate. net/figure/Principle - of - a - bacterial - bioluminescent - biosensor_fig1_285530607

4. Forensic Significance

Food contamination can cause long - term and quite often excessive consumption of poisonous substance and in some extreme cases, very dangerous pathologies incurable by medical treatment. The two most prevalent threats for consumers are optimal healthy state for life and general good health. The utilization of a standardized approach that is commonly used in criminal investigations along with the practice of correct food science and safety principles will bring out quick and accurate identification of the central problem [80].

5. Conclusion

Food poisoning is caused by early invasions of the body by pathogenic bacteria in food, which is why food safety procedures are essential. Both traditional and conventional methods have its own advantages and disadvantages. Analytical limitations like sample preparation, methods opted for pathogen detection should be taken into consideration in future studies. The development of a novel and reliable method is the key priority for the research team, where the realization of the goals and objectives is accompanied by accuracy, precision, validation, economy, environmental nature, and commercialization potential. The food contaminants and the materials of their origin are such as living organisms, the microbes, for instance, are the common bacteria (Salmonella, E. coli), the pesticide residues, and the metallic compounds. There were lots of categories during the contamination of food, identification of such contaminants plays a crucial role.

Methods of detecting food contaminants have been a function of time. The old methods include culture - based methods and biochemical testing are still applicable because they are effective and the protocols are set. However, these methods are time consuming and take more resources, which sometimes delays responses to contamination incidents. Advanced detection techniques include molecular biology methods like PCR, immunological assays such as ELISA, and

biosensors, which provide results in a very short time with high sensitivity and specificity. These modern approaches allow quicker identification of pathogens and contaminants, thus facilitating timely interventions crucial for public health protection. Preventive measures should also minimize the risks of food contamination equally. Basic precautions to have a minimum risk of food contamination include hygienic handling of foods, proper temperature of cooking, and not storing raw and cooked foods in close proximity to each other. Another essential step would be public awareness campaigns by the public sector and educational institutions regarding consumers who would enlighten choices through the practice of safe food preparation methods.

Though great advances have been made with technologies and prevention, many challenges still surround proper food safety management. Traceability and accountability to those causing contamination incidents are complicated due to globalization of food supply chains. Moreover, pathogens continue to be a major challenge to public health with increased antimicrobial resistance. Challenges to address these issues can be realized only through a cooperative approach from governments, regulatory agencies, the food industry, and consumers in establishing responsive food safety systems that accommodate the changing circumstances.

It is complex but important work, involving a clear understanding of what causes food contamination, appropriate methods for its detection, and taking action to prevent its occurrence. Through innovative technologies and public education sweats, we can drop the prevalence of foodborne ails and cover global health through the prioritization of food safety, nonstop exploration into arising pollutants and new discovery methodologies will be a vital step in conforming to the evolving geography of food safety challenges. The line is that only a cooperative approach involving all stakeholders will ensure that the food force remains safe and healthy for consumers worldwide.

References

[1] FoodDocs (n. d.) *What is food contamination?* FoodDocs. Available at: https: //www.fooddocs. com/post/what - is - food contamination#: ~: text=Food%20contamination%20describes%20the%20event%20at%20which%20a, and%20chemical%2C%20depending%20on%20its%20nature%20and%20origin (Accessed: 19 December 2024).

[2] Ling, Z., Yang, L., Zhang, W., Yao, T. and Xu, H., 2024. Detection of food contaminants: A review of established rapid analytical techniques and their applications and limitations. *Food Safety and Health*, *2* (1), pp.72 - 95.

[3] Aladhadh, M., 2023. A review of modern methods for the detection of foodborne pathogens. *Microorganisms*, *11* (5), p.1111.

[4] Hariri, S., 2022. Detection of escherichia coli in food samples using culture and polymerase chain reaction methods. *Cureus*, *14* (12).

[5] Kristanti, R. A., Hadibarata, T., Syafrudin, M., Yılmaz, M. and Abdullah, S., 2022. Microbiological contaminants in drinking water: Current status and challenges. *Water, Air, & Soil Pollution*, *233* (8), p.299.

[6] Naidu, R., Biswas, B., Willett, I. R., Cribb, J., Singh, B. K., Nathanail, C. P., Coulon, F., Semple, K. T., Jones, K. C., Barclay, A. and Aitken, R. J., 2021. Chemical pollution: A growing peril and potential catastrophic risk to humanity. *Environment International*, *156*, p.106616.

[7] Collier, E. (2019) *What are the four types of food contamination?* High Speed Training, 26 August. Available at: https: //www.highspeedtraining. co. uk/hub/four - types - contamination/ (Accessed: 19 December 2024).

[8] Amani, J., Mirhosseini, S. A. and Fooladi, A. A. I., 2014. A review approaches to identify enteric bacterial pathogens. *Jundishapur journal of microbiology*, *8* (2), p. e17473.

[9] Yeni, F., Yavaş, S., Alpas, H. A. M. I. and Soyer, Y. E. S. I. M., 2016. Most common foodborne pathogens and mycotoxins on fresh produce: a review of recent outbreaks. *Critical reviews in food science and nutrition*, *56* (9), pp.1532 - 1544.

[10] Pandey, P. K., Kass, P. H., Soupir, M. L., Biswas, S. and Singh, V. P., 2014. Contamination of water resources by pathogenic bacteria. *Amb Express*, *4*, pp.1 - 16.

[11] Shwaiki, L. N., Arendt, E. K., Lynch, K. M. and Thery, T. L., 2019. Inhibitory effect of four novel synthetic peptides on food spoilage yeasts. *International journal of food microbiology*, *300*, pp.43 - 52.

[12] Kabiraz, M. P., Majumdar, P. R., Mahmud, M. C., Bhowmik, S. and Ali, A., 2023. Conventional and advanced detection techniques of foodborne pathogens: A comprehensive review. *Heliyon*, *9* (4).

[13] Clayton, J. (2019) *Impact of foodborne illness in a healthcare setting.* PDI Healthcare, 1 October. Available at: https: //pdihc. com/blog/impact - of - foodborne - illness - in - a - healthcare - setting/ (Accessed: 19 December 2024)

[14] Abdolshahi, A. and Shokrollahi Yancheshmeh, B., 2020. Food contamination. In: Mycotoxins and food safety. IntechOpen. Available at: http: //dx. doi. org/10.5772/intechopen.89802 [Accessed 19 December 2024].

[15] Mead, P. S., Slutsker, L., Dietz, V., McCaig, L. F., Bresee, J. S., Shapiro, C., Griffin, P. M. and Tauxe, R. V., 1999. Food - related illness and death in the United States. *Emerging infectious diseases*, *5* (5), p.607.

[16] Guo, W., Pan, B., Sakkiah, S., Yavas, G., Ge, W., Zou, W., Tong, W. and Hong, H., 2019. Persistent organic pollutants in food: contamination sources, health effects and detection methods. *International journal of environmental research and public health*, *16* (22), p.4361.

[17] Alum, E. A., Urom, S. M. O. C. and Ben, C. M. A., 2016. Microbiological contamination of food: the mechanisms, impacts and prevention. *Int. J. Sci. Technol. Res*, *5* (3), pp.65 - 78.

[18] Priyanka, B., Patil, R. K. and Dwarakanath, S., 2016. A review on detection methods used for foodborne pathogens. *Indian Journal of Medical Research*, *144* (3), pp.327 - 338.

[19] Hariri, S., 2022. Detection of escherichia coli in food samples using culture and polymerase chain reaction methods. *Cureus*, *14* (12).
[20] Swartz, M. N., 2002. Human diseases caused by foodborne pathogens of animal origin. *Clinical Infectious Diseases*, *34* (Supplement_3), pp. S111 - S122.
[21] Dahlin, J. L., Sittampalam, G. S., Coussens, N. P., Devanarayan, V., Weidner, J. R., Iversen, P. W., Haas, J. V., Bronson, D. D., Trask Jr, O. J., Wiernicki, T. R. and Kahl, S. D., 2019. Basic guidelines for reporting non - clinical data. *Assay Guidance Manual [Internet]*.
[22] Gandhi, M. and Chikindas, M. L., 2007. Listeria: a foodborne pathogen that knows how to survive. *International journal of food microbiology*, *113* (1), pp.1 - 15.
[23] Abdallah, M. F., Van Hassel, W. H., Andjelkovic, M., Wilmotte, A. and Rajkovic, A., 2021. Cyanotoxins and food contamination in developing countries: Review of their types, toxicity, analysis, occurrence and mitigation strategies. *Toxins*, *13* (11), p.786.
[24] Shaltout, F. A., 2024. Ways of Food Contamination, Its Impact and Prevention. *Food Sci. Nutr. Technol*, *9*, pp.1 - 8.
[25] Bintsis, T., 2017. Foodborne pathogens. *AIMS microbiology*, *3* (3), p.529.
[26] Akbar, A. and Anal, A. K., 2011. Food safety concerns and food - borne pathogens, Salmonella, Escherichia coli and Campylobacter. *FUUAST journal of Biology*, *1* (1 June), pp.5 - 17.
[27] Begley, M. and Hill, C., 2015. Stress adaptation in foodborne pathogens. *Annual review of food science and technology*, *6* (1), pp.191 - 210.
[28] Elbehiry, A., Abalkhail, A., Marzouk, E., Elmanssury, A. E., Almuzaini, A. M., Alfheeaid, H., Alshahrani, M. T., Huraysh, N., Ibrahem, M., Alzaben, F. and Alanazi, F., 2023. An overview of the public health challenges in diagnosing and controlling human foodborne pathogens. *Vaccines*, *11* (4), p.725.
[29] World Health Organization (2006) *Five keys to safer food manual.* Geneva: World Health Organization. Available at: https: //www.who. int/publications/i/item/9789241594639 (Accessed: 19 December 2024).
[30] Alahi, M. E. E. and Mukhopadhyay, S. C., 2017. Detection methodologies for pathogen and toxins: A review. *Sensors*, *17* (8), p.1885.
[31] Vasavada, P. C., Lee, A. and Betts, R., 2020. Conventional and novel rapid methods for detection and enumeration of microorganisms. *Food safety engineering*, pp.85 - 128.
[32] McLain, J. E., Cytryn, E., Durso, L. M. and Young, S., 2016. Culture-based methods for detection of antibiotic resistance in agroecosystems: Advantages, challenges, and gaps in knowledge. *Journal of environmental quality*, *45* (2), pp.432 - 440.
[33] *Cultivation of bacteria and culture methods* (2016) Slideshare, 6 November. Available at: https: //www.slideshare. net/slideshow/cultivation - of - bacteria - and - culture - methods/68254885 (Accessed: 19 December 2024).
[34] Rao, S. (n. d.) *Bacterial culture media.* Available at: https: //www.microrao. com/micronotes/pg/culture_media. pdf (Accessed: 19 December 2024).
[35] Iqbal, M. (2023) *Culturing techniques – Types and methods.* Microbial Notes, 28 January. Available at: https: //microbialnotes. com/culturing - techniques - types - and - methods (Accessed: 19 December 2024).
[36] Chauhan, A., Jindal, T., Chauhan, A. and Jindal, T., 2020. Biochemical and molecular methods for bacterial identification. *Microbiological methods for environment, food and pharmaceutical analysis*, pp.425 - 468.
[37] Moore, S. (2024) *Biochemical tests for microbial identification.* News - Medical, 26 November. Available at: https: //www.news - medical. net/life - sciences/Biochemical - Tests - for - Microbial - Identification. aspx (Accessed: 19 December 2024).
[38] Lab Tests Guide (n. d.) *Biochemical tests.* Available at: https: //www.labtestsguide. com/biochemical - tests#google_vignette (Accessed: 19 December 2024).
[39] Law, J. W. F., Ab Mutalib, N. S., Chan, K. G. and Lee, L. H., 2015. Rapid methods for the detection of foodborne bacterial pathogens: principles, applications, advantages and limitations. *Frontiers in microbiology*, *5*, p.770.
[40] Notermans, S. and Wernars, K., 1991. Immunological methods for detection of foodborne pathogens and their toxins. *International journal of food microbiology*, *12* (1), pp.91 - 102.
[41] Cox, K. L., Devanarayan, V., Kriauciunas, A., Manetta, J., Montrose, C. and Sittampalam, S., 2019. Immunoassay methods. *Assay Guidance Manual [Internet]*.
[42] Choy, W. F., Lim, P. L. and Ng, M. H., 1988. A comparison of immunological methods for the detection of Trichinella spiralis antigen. *Journal of immunological methods*, *113* (1), pp.17 - 24.
[43] Yolken, R. H., 1980. Enzyme - linked immunosorbent assay (ELISA): a practical tool for rapid diagnosis of viruses and other infectious agents. *The Yale journal of biology and medicine*, *53* (1), p.85.
[44] Twala, P. P., Mitema, A., Baburam, C. and Feto, N. A., 2020. Breakthroughs in the discovery and use of different peroxidase isoforms of microbial origin. *AIMS microbiology*, *6* (3), p.330.
[45] Yeni, F., Acar, S., Polat, Ö. G., Soyer, Y. E. Ş. İ. M. and Alpas, H. A. M. İ., 2014. Rapid and standardized methods for detection of foodborne pathogens and mycotoxins on fresh produce. *Food Control*, *40*, pp.359 - 367.
[46] Shah, K. and Maghsoudlou, P., 2016. Enzyme - linked immunosorbent assay (ELISA): the basics. *British journal of hospital medicine*, *77* (7), pp. C98 - C101.
[47] Vass, M., Diblikova, I., Cernoch, I. and Franek, M., 2008. ELISA for semicarbazide and its application for screening in food contamination. *Analytica Chimica Acta*, *608* (1), pp.86 - 94.
[48] Vázquez - Pertejo, M. T. (2022) *Nucleic acid - based identification methods for infectious disease.* Wellington Regional Medical Center, October.
[49] Li, M., Yin, F., Song, L., Mao, X., Li, F., Fan, C., Zuo, X. and Xia, Q., 2021. Nucleic acid tests for clinical translation. *Chemical Reviews*, *121* (17), pp.10469 - 10558.

[50] Wolcott, M. J., 1992. Advances in nucleic acid - based detection methods. *Clinical microbiology reviews*, *5* (4), pp.370 - 386.
[51] Barghouthi, S. A., 2011. A universal method for the identification of bacteria based on general PCR primers. *Indian journal of microbiology*, *51*, pp.430 - 444.
[52] Barken, K. B., Haagensen, J. A. and Tolker - Nielsen, T., 2007. Advances in nucleic acid - based diagnostics of bacterial infections. *Clinica Chimica Acta*, *384* (1 - 2), pp.1 - 11.
[53] Ceuppens, S., Li, D., Uyttendaele, M., Renault, P., Ross, P., Ranst, M. V., Cocolin, L. and Donaghy, J., 2014. Molecular methods in food safety microbiology: interpretation and implications of nucleic acid detection. *Comprehensive Reviews in Food Science and Food Safety*, *13* (4), pp.551 - 577.
[54] Zhang, M., Ye, J., He, J. S., Zhang, F., Ping, J., Qian, C. and Wu, J., 2020. Visual detection for nucleic acid - based techniques as potential on - site detection methods. A review. *Analytica Chimica Acta*, *1099*, pp.1 - 15.
[55] Zhang, Y., Zhu, L., Zhang, Y., He, P. and Wang, Q., 2018. Simultaneous detection of three foodborne pathogenic bacteria in food samples by microchip capillary electrophoresis in combination with polymerase chain reaction. *Journal of Chromatography a*, *1555*, pp.100 - 105.
[56] Singh, J., Birbian, N., Sinha, S. and Goswami, A., 2014. A critical review on PCR, its types and applications. *Int. J. Adv. Res. Biol. Sci*, *1* (7), pp.65 - 80.
[57] Rodriguez, R. S., O'Keefe, T. L., Froehlich, C., Lewis, R. E., Sheldon, T. R. and Haynes, C. L., 2020. Sensing food contaminants: advances in analytical methods and techniques. *Analytical Chemistry*, *93* (1), pp.23 - 40.
[58] Dias, G. and Rathnayaka, U., 2018. Fluorescence in situ hybridization (FISH) in food pathogen detection. *Int. J. Mol. Biol*, *3*, pp.143 - 149.
[59] Book DNA Probes for Infectious Diseases Tenover, F. C.[at]9780849361760 https: //books. google. co. in/books?id=llq99N - okzkC 1988 Taylor & Francis
[60] Yan Zeng, Peng Qi, Yingwen Wang, Chao Chen, Dun Zhang, DNA pom - pom nanostructure as a multifunctional platform for pathogenic bacteria determination and inactivation, Biosensors and Bioelectronics, Volume 177, 2021, 112982, ISSN 0956 - 5663, https: //doi. org/10.1016/j. bios.2021.112982.
[61] Shuang, Y., Tang, Y., Yan, M., Aguilar, Z. P., Lai, W., & Xu, H., 2019. A fluorescent cascade amplification method for sensitive detection of Salmonella based on magnetic Fe3O4 nanoparticles and hybridization chain reaction. *Sensors and Actuators B: Chemical*, 279, pp.31 - 37. doi: 10.1016/j. snb.2018.09.091.
[62] Zhao, J., Guo, Y., Ma, X., Liu, S., Sun, C., Cai, M., Chi, Y. and Xu, K., 2023. The Application of Hybridization Chain Reaction in the Detection of Foodborne Pathogens. *Foods*, *12* (22), p.4067.
[63] Chatwal, G. R., 2022. *Instrumental methods of chemical analysis*. Himalaya publishing house.
[64] Workman, J. (2024) 'A Brief Review of the Latest Spectroscopic Research in Environmental Analysis', *Spectroscopy*, 18 June. Available at: https: //doi. org/10.56530/spectroscopy. wd2586t9 (Accessed: 27 January 2025).
[65] Das, R. S. and Agrawal, Y. K., 2011. Raman spectroscopy: Recent advancements, techniques and applications. *Vibrational spectroscopy*, *57* (2), pp.163 - 176.
[66] Neng, J., Zhang, Q. and Sun, P., 2020. Application of surface - enhanced Raman spectroscopy in fast detection of toxic and harmful substances in food. *Biosensors and Bioelectronics*, *167*, p.112480.
[67] Berthomieu, C. and Hienerwadel, R., 2009. Fourier transform infrared (FTIR) spectroscopy. *Photosynthesis research*, *101*, pp.157 - 170.
[68] Carreras, H. Z., 2021. NMR spectroscopy principles, interpreting an nmr spectrum and common problems. *Technology Networks Analysis and Separations*.
[69] Johnson Jr, C. S., 1999. Diffusion ordered nuclear magnetic resonance spectroscopy: principles and applications. *Progress in nuclear magnetic resonance spectroscopy*, *34* (3 - 4), pp.203 - 256.
[70] Creative Biolabs (n. d.) *Array techniques.* Available at: https: //www.creative - biolabs. com/drug - discovery/diagnostics/array - technique. htm#: ~: text=Among%20all%20kinds%20of%20in%20vitro%20diagnostic%20%28IVD%29, one%20of%20the%20most%20important%20detection%20technology%20modules (Accessed: 19 December 2024).
[71] Chadha, U., Bhardwaj, P., Agarwal, R., Rawat, P., Agarwal, R., Gupta, I., Panjwani, M., Singh, S., Ahuja, C., Selvaraj, S. K. and Banavoth, M., 2022. Recent progress and growth in biosensors technology: A critical review. *Journal of Industrial and Engineering Chemistry*, *109*, pp.21 - 51.
[72] Singh, A. K., Mittal, S., Das, M., Saharia, A. and Tiwari, M., 2023. Optical biosensors: A decade in review. *Alexandria Engineering Journal*, *67*, pp.673 - 691.
[73] Zhang, Z., Zhou, J. & Du, X., 2019. Electrochemical biosensors for detection of foodborne pathogens. *Micromachines*, 10 (4), p.222. Available at: https: //doi. org/10.3390/mi10040222 [Accessed 26 January 2025].
[74] Damborsky, P., Vitel, J. & Katrlik, J., 2016. Optical biosensors. *Essays in Biochemistry*, 60 (1), pp.91–100. doi: 10.1042/ebc20150010.
[75] Meliana, C., Liu, J., Show, P. L. and Low, S. S., 2024. Biosensor in smart food traceability system for food safety and security. *Bioengineered*, *15* (1), p.2310908.
[76] Razmi, N., Hasanzadeh, M., Willander, M. and Nur, O., 2020. Recent progress on the electrochemical biosensing of Escherichia coli O157: H7: Material and methods overview. *Biosensors*, *10* (5), p.54.
[77] Curulli, A., 2021. Electrochemical biosensors in food safety: Challenges and perspectives. *Molecules*, *26* (10), p.2940.
[78] Khaleque, M. A., Hossain, S. I., Ali, M. R., Aly, M. A. S., Abuelmakarem, H. S., Al Mamun, M. S. and Khan, M. Z. H., 2024. Bioreceptor modified electrochemical biosensors for the detection of life threating pathogenic bacteria: a review. *RSC advances*, *14* (39), pp.28487 - 28515.
[79] Mahari, S. and Gandhi, S., 2022. Recent advances in electrochemical biosensors for the detection of

salmonellosis: Current prospective and challenges. *Biosensors*, *12* (6), p.365.

[80] Rather, I. A., Koh, W. Y., Paek, W. K. and Lim, J., 2017. The sources of chemical contaminants in food and their health implications. *Frontiers in Pharmacology*, 8, p.830. Available at: https: //doi. org/10.3389/fphar.2017.00830 [Accessed 19 December 2024].