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Review

Food Quality, Drug Safety, and Increasing Public Health Measures in Supply Chain Management

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Abstract: Over the last decade, there has been an increased interest in public health measures concerning food quality and drug safety in supply chains and logistics operations. Against this backdrop, this study systematically reviewed the extant literature to identify gaps in studying food quality and drug safety, the proposed solutions to these issues, and potential future research directions. This study utilized content analysis. The objectives of the review were to (1) identify the factors affecting food quality and possible solutions to improve results, (2) analyze the factors that affect drug safety and identify ways to mitigate them through proper management; and (3) establish integrated supply chains for food and drugs by implementing modern technologies, followed by one another to ensure a multi-layered cross-verification cascade and resource management at the different phases to ensure quality, safety, and sustainability for the benefit of public health. This review investigated and identified the most recent trends and technologies used for successfully integrated supply chains that can guarantee food quality and drug safety. Using appropriate keywords, 298 articles were identified, and 205 were shortlisted for the analysis. All analysis and conclusions are based on the available literature. The outcomes of this paper identify new research directions in public health and supply chain management.

Keywords: food quality; drug safety; supply chain management; public health; health; safety

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1. Introduction

Efficient supply chain management plays a critical role in food quality and drug safety because supply chains must meet demands for food and drugs for the world's population [1]. These supply chains encompass many stages, such as, procurement, production, and processing, storing, distribution, and interconnectivity of various constituents in the food and drug supply chains [2]. Researchers and practitioners have taken a serious look at how these supply chains have been managed over the past decade [3].

One government objective is to protect a nation's food and drug supplies, and indeed, this is the mission of food and drug administrations of countries worldwide. For example, in its mission statement, the United States Food and Drug Administration (FDA) states that it is "responsible for protecting public health by ensuring efficacy, safety, and security of human and veterinary drugs, biological products, and medical devices, by ensuring the safety of our nation's food supply, cosmetics, and products that emit radiation" [4].

Food supply chains (FSCs) constitute a complex network of systems ranging from the farm to the factory to the final consumer. The food supply chain has characteristics similar to those of the conventional supply chains. Still, it has specific characteristics that make its management more challenging as food is a perishable commodity [5]. FSCs have faced challenges such as adulteration, food wastage, price volatility, nutrition security, climate-controlled variability, declining yields, and governance issues. Previous research has examined the issues related to FSCs [6]. Zhao et al. [7] assessed the use of blockchain

technology in FSCs. According to them, state-of-the-art blockchain technology can be implemented alongside the internet of things (IOT) in FSC's information security management, manufacturing, traceability, and food waste prevention.

Developed and developing countries have unsafe food supplies. Food organizations must strengthen their processes to counter various potential hazards to keep the world's population safe and healthy. In addition to hazards related to food, food security, which encompasses access to safe food, rising food prices, and declining yields, has become an issue [8]. Low-quality food contributes to 678,000 deaths yearly in the United States [9]. Additionally, researchers surveyed the United States to determine the number of people affected by poor food quality. Based on mortality and health status information from the National Health and Nutrition Examination Survey (2009–2020), the researchers analyzed data on adults (≥20 years) from the study. Among the total participants in the study (n = 25,247), 17.6% reported food quality below the recommended levels [10].

Food counterfeiting has also caused terrible damage to public health on social and economic levels throughout history. For instance, there have been reports of 2.5–3 million people consuming contaminated feed from chickens. Another food-related incident was reported in China, where melamine contamination of milk harmed more than 300,000 people, including babies. Lee and Yoon [11] reported 3000 deaths due to food counterfeiting in the United States, Jung et al. [12] reported 180 deaths in the United Kingdom, Onwujekwe and Ezemba [13] reported 137,000 deaths in Africa, Dada et al. [14] reported 175,000 deaths in Asia, and Kerr et al. [15] reported 80 deaths in Australia.

The fight against drug counterfeiting is more profound than food because it poses a greater threat to public health [16]. Counterfeit drugs are a serious international issue that has various effects on public health and safety and are a primary cause of drug resistance that results in patient death. Due to its supply coming from multiple countries, counterfeit drugs are rising worldwide. The impact of counterfeit drugs is medical and economic. There has been a decrease in patient adherence to their medications due to the increasing concern about counterfeit drugs. For example, a patient receiving injections for anaemia after a liver transplant did not experience any therapeutic effect after eight weeks because the medication used for the therapy was counterfeit. A heparin recall in 2008 occurred because the active drug was replaced with a cheaper or less effective substance supplied from China, which resulted in 81 deaths [17]. In 2009, patients reported that uncontrollable blood sugar levels were caused by ineffective insulin that was not stored or handled correctly, thus losing potency [17]. In February 2012, counterfeit versions of the cancer drug Avastin were discovered that contained only starch and salt and no bioactive ingredients.

It is difficult to prevent the entry of counterfeit drugs into the United States, as most active pharmaceutical ingredients (APIs) are imported from all over the world. Buyers are interested in having active medications for a lower price. Increasing internet/online pharmacies make the regulation of drug safety more difficult. More than 36 million Americans purchase their medicines from online pharmacies without knowing they are counterfeit and harming their health. According to the World Health Organization (WHO), around 30% of counterfeit medications are sold in Asia, Africa, and Latin America. Approximately 10% of medication used globally is counterfeit. Counterfeit medicines can harm public health or result in no progress in patients' health if there is no active ingredient in the medication's compounds [17].

1.1. Purpose of This Review

This review examines various aspects contributing to food and drug supply chain issues in the extant literature on the topic. It can help researchers, supply chain organizations, and government policymakers to identify primary considerations in exploring various operations' susceptibilities and strategies to grow resilience to enduring and mounting hazards related to food and drug supplies [18]. However, this issue is complex. Food scientists and pharmaceutical producers have found that no single solution can guarantee the quality of products in the future [19]. As a first step, this paper discusses issues of

food quality with an overview of its scale. Food safety has four main components, which are availability, accessibility, stability, and utilization, but the focus of this paper will be specifically on food quality which is a component of utilization and stability. The paper then discusses the solutions applicable to overcome these issues. The following is a discussion of drug safety issues and explores ways to overcome these issues and methods to prevent the counterfeiting of drugs by exploring the use of various solutions such as smart tools, technologies, and a focus on the importance of staff training to ensure high-quality standards for public health.

1.2. State of the Review

1.2.1. Food Quality

Researchers have contributed to addressing food quality issues in the past. George et al. [20] proposed a model for ensuring quality in restaurant supply chains based on the mathematical prototype and blockchain technology. Aamer et al. [21] examined the potential of IOT for improving the functionality of FSCs by systematically analyzing the challenges involved. Tan et al. [22] conducted a thematic analysis of how Walmart uses blockchain technology to ensure the stability of edible products in FSCs. Bernstad et al. [23] studied the impact of lifecycle assessment on reducing the amount of food denatured by any microbiological and chemical agent in transportation and supply chain management. Zhu et al. [24] presented a model-based review that discussed food spoilage-related radiation exposures and their future directions. Sohail et al. [25] discussed the role of advanced packaging technologies in increasing the quality of food products in terms of controlling microbial growth and gas concentration and providing convenience and easiness to its users in the form of time–temperature indication. Scholten et al. [26] found that implementing learning mechanisms is essential for supply chain staff to perform their routine work effectively.

1.2.2. Drug Safety

Kumar and Tripathi [27] discussed drug safety issues in PSCs and suggested their elucidations by using blockchain technology to trace any inactive ingredient used to counterfeit drugs. Jamil et al. [28] proposed a novel framework for the smart hospital to avoid counterfeiting using Hyperledger Fabric to handle secure drug supply chain records. They also suggested a benchmarking tool to conduct the performance of the designed system in terms of transactions per second, transaction latency, and resource utilization. Marques et al. [29] developed a multi-objective collaborative decision-making model to implement regulatory policies to encounter fake drugs by considering the objection of both retailers and distributors. Krämer et al. [30] emphasized controlling microbiological agents while packaging medications such as hormones and monoclonal antibodies. Gunnarsson et al. [31] suggested developing an effects-based environmental assessment to facilitate efficient approaches for pharmaceutical toxicity testing.

Despite the greater number of reviews, to our knowledge, no previous studies had analyzed the potential integration of both FSCs and PSCs in a single framework that can encounter the challenges faced by these supply chains. Previous research tried to focus on a single supply chain and elucidate the issues associated with it from different perspectives without looking at the bigger picture of similarities of the considered supply chains and trying to integrate the results. Both supply chains have similar issues due to their importance in public health safety. To address these problems effectively, there should be an integrated approach to using a blend of solutions and technologies to cover all the loopholes of modern-day supply chains by creating a multi-layered cross-verification cascade at each level of a supply chain to prevent it from any random or intentional disruption. It will lead to the success of the management of supply chains to meet the requirements of society and will ensure public health on permanent grounds.

1.3. Review Objectives

The purpose of this review is to improve public health by identifying factors affecting food quality, drug safety, and effective solutions in the supply chain systems. This is conducted through the implementation of novel tools, emerging technologies, integrating policies, and focusing on critical control points, their assessment, and evaluation after a regular interval in all phases of the supply chains to achieve the desired results. Furthermore, this review will investigate and discuss methods that may assist in resolving similar issues related to FSCs and PSCs.

The following steps can be carried out to achieve this:

1. Identify the factors affecting food quality and possible solutions to improve results.
2. Analyze the factors that affect drug safety and identify ways to mitigate them through proper supply chain management.
3. Establish integrated supply chains for food and drugs by implementing modern technologies, followed by one another, to ensure a multi-layered, cross-verification cascade and resource management at the different phases to ensure quality, safety, and sustainability for the benefits of public health.

2. Review Methodology

This paper uses a systematic literature review to highlight the gap in previously published literature and explore reliable information. Food quality and drug safety are two significant public health concerns that require an analysis of a wide range of present literature to identify food and drug safety measures, challenges and solutions, emerging trends, and strategies to mitigate the factors causing obstacles to two key public health issues. An analysis of the emerging trends in food and drug supply chains is presented from already published articles. The systematic review was selected as a methodological approach to describe the empirically theoretically-based available articles [32]. Figure 1 elaborates on this review's methodology.

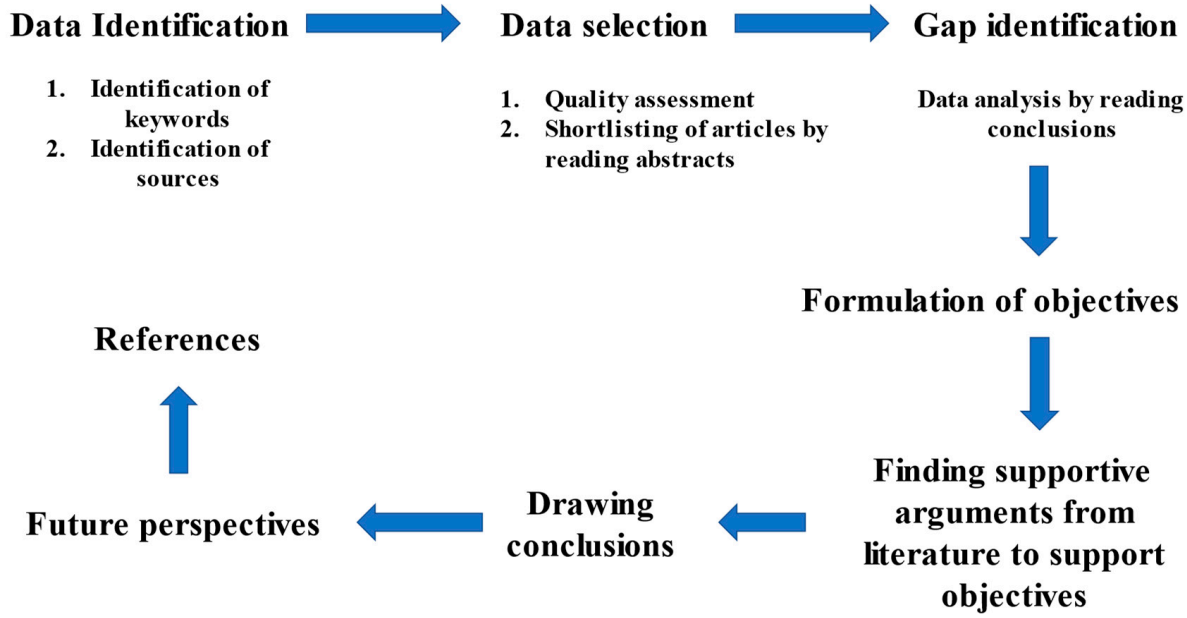

Figure 1. Review of methodology.

2.1. Data Identification

The literature search was conducted with the help of library search engines, such as "Web of Science", "Scopus", "ScienceDirect", "Emerald Insight", "Wiley", "IEEE", "ResearchGate", and "Google Scholar". By using all these search engines, we could ensure a diverse knowledge base and demonstrate an increased interest in food safety and drug safety through understanding the main concepts. Articles from these renowned journals

were retrieved, assuming that applying these criteria would exclude sanctioned peer-reviewed research [33]. In the journals mentioned above, there are a variety of publications on food quality and drug safety and their importance in achieving safe and smooth operation for FSCs and PSCs. Several keywords were used to identify articles at the initial stage, such as food quality, drug safety, supply chain management, and public health. There are times when words such as food supply chains or drug supply chains and their effectiveness or modern tools for food quality or drug safety were combined. AND and OR operators were employed to make the research more comprehensive [32].

Table 1 describes the methodology for identifying papers to review and search based on keywords.

Table 1. Identification of keywords.

Keywords	Search Strings	Databases
1. Identify factors that affect food quality and proposed solutions to achieve public health safety.	Factors (OR issues) affect food quality AND Solutions for food quality AND Food supply chain	Web of Science Scopus ScienceDirect Emerald insight Wiley IEEE Research gate Google Scholar
2. Identify factors that affect drug safety and proposed solutions to achieve public health safety.	Factors (OR issues) affect food quality AND Solutions for food quality AND Pharmaceutical supply chain	
3. Identify similar solutions to overcome public health issues in the food and drug industries and achieve an integrated supply chain.	Effective solutions (OR tools) AND Emerging technologies AND Integrated supply chain AND Food quality (OR Drug safety) AND Similar issues	

2.2. Data Selection

To achieve the review objectives, the selected papers for the review were based on the papers published in English, with publication dates ranging from 2016 to the present. Some papers from earlier periods were selected because they contained basic statistics necessary for understanding this review's purpose. The abstracts and methodologies of initially selected 298 articles were then read and irrelevant articles were discarded [34]. The irrelevant articles were determined and excluded in three phases, as detailed in Table 2. Two hundred and five (205) articles were chosen for further discussion and analysis of food quality, drug safety, and supply chain issues and their effective solutions. The shortlisted articles were examined to gain a deep understanding of the administrative hierarchy of food chains, transportation challenges, environmental, chemical, physical, and microbiological hazards that food and drugs encountered due to certain factors around the globe, and to determine effective, affordable solutions to avoid such conditions in the future.

Table 2. Exclusion of irrelevant papers.

Exclusions	Description
1. Initial search (Filter 1)	The search engines were used, and the abstract, introduction, and conclusion of articles in selected journals were skimmed. This search generated 298 papers.
2. First exclusion (Filter 2)	The filter generated 245 papers. Duplicate papers were removed, and papers irrelevant to food or drug issues in their prospective supply chains or those that could be classified as similar for both were also removed.
3. Second exclusion (Filter 3)	The filter was applied to refine the final selection and generated 205 articles. Only those with relevant information for each objective of this study, such as basic information for the introduction, factors that affect food quality and drug safety, and solutions to achieve an integrated supply chain and ensure public health safety, were included.

Table 3 details the number of articles and topics studied for food quality and drug safety and region of the study.

Table 3. Number of articles and topics studied for food and for drugs, region, and keywords.

	Food	Drugs
Number of articles	112	56
Original research	84	48
Literature review	28	8
Region		
Africa	7	7
Asia	12	9
Europe	10	4
North America	7	4
Oceania	2	-
South America	6	4
Australia and Pacific	3	-
Worldwide	55	36

Note: The most common keywords for food were supply chain management, agri-food, stochastic demand, perishable food, food safety, food quality, food sustainability, food risks, food technology, food traceability, food counterfeiting, food borne, unhealthy food, waste reduction, intelligent packaging, microbiological contamination, GMO food, LCA, short supply chain, food cold chain, and RLs. The most common keywords for drugs were perishable drugs, drug safety, pharmaceutical risks, drug technologies, drug traceability, drug counterfeiting, smart packaging, biological medicines, microbial contamination, safe drug disposal, GMO, RLs, and complexity reduction.

2.3. Gap Identification

Thirteen (13) articles discussed the issues concerning food quality in various ways, and ten (10) articles enlisted the issues for drug safety in supply chain management; those studies also explored solutions to create an effective supply chain to cope with the challenges. During the last decade, certain changes have arisen not only in consumer attitudes but also for different stakeholders of the supply chains. The four most common gradual changes are uncertainty [35], consumer preferences [36], the volume of demand [37], and logistics operations [38]. Despite this outcome, it is unsurprising because the burden is on the supply and distribution networks and not on the primary production of food and drugs. Therefore, a need exists for a better management plan to better utilize all the available resources for the most critical public health issues such as food quality and drug safety to ensure that the world's population gets fed and genuine medications are available even in faraway places. These changes will allow a blend of modern tools and technologies and create a multi-layered cross-verification cascade to align logistics operations, addressing public health issues in an integrated manner. These changes will also demand efficient resource management to address all hazards affecting food quality and drug safety.

3. Issues Affecting Food Quality and Drug Safety

This section explores how food quality and drug safety contribute to public health and the associated issues. Several issues are common to both supply chains, while some are limited to only one of those mentioned above. Modern supply chains are interconnected systems responsible for production, processing, storage, and distribution activities until delivery to final customers. To manage these activities in a hierarchical way, processes must exist from higher management down to sales representatives to ensure the quality, safety, and monitoring of inventory to inform the production units. Consequently, supply chain staff should be skilled in food quality and drug safety procedures to ensure the use of modern tools in processing and operations to deliver safe and healthy food to the public [39].

An FSC describes a network of complex systems responsible for the harvest, processing of raw materials, manufacture, and distribution to final consumers. Manufacturers must be able to manufacture on time because food is often perishable, which causes financial hardships or wastage [40]. During the last decade, researchers have become more interested

in FSCs because food is produced and transported over vast distances across the globe. These distances have made FSCs longer and more complex, exposing them to greater risks. The world has become more concerned about food quality because the safer the food, the lower the chances of catching a disease [41]. As a result of more significant risks in FSCs, management is more challenging than in other supply chains. Food products are at a higher risk because they are derived from crops, which are seasonal [1], but consumption is year-round. Food products have long supply periods that cannot be entirely surmounted. Manufacturing, processing, storing, and delivering food are complex. In addition, the perishable nature of food products necessitates special handling tools during inventory management [42]. Figure 2 outlines the stakeholders at each stage of conventional FSC.

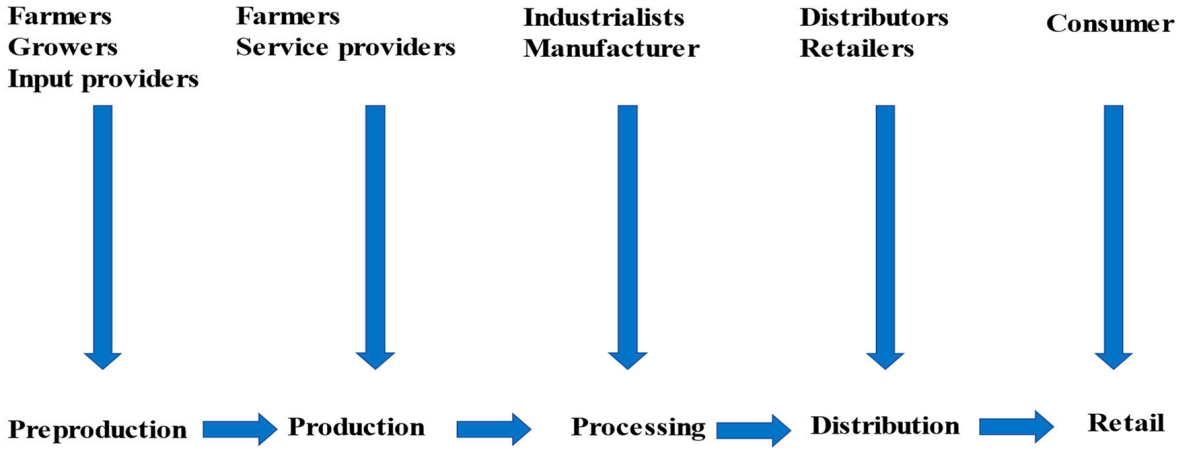

Figure 2. Stakeholders at each stage of conventional FSC.

Food quality is a basic expectation of every buyer, consumer, and stakeholder closely monitoring food processing companies' products and practices [43]. Companies are hiring workers to ensure that their consumers are aware of the food quality practices during the manufacture and processing of food products [44]. These dynamic capabilities create a competitive market. Manufacturers have become more concerned with food safety procedures to increase revenue because consumers know the food safety level and empirical validation. As a result, supply chain managers with dynamic capabilities and strategic planning are vital for generating high revenues in the market and success in a competitive market [45]. The significant increase in the world's population has dramatically boosted the demand for food. Thus, sustainably feeding the world population by providing quality food is a considerable challenge. Technological and scientific development, institutional intervention, business investment, government policy, and innovations have resulted in several hazards to food products, nutritional value, shelf life, and safety [46]. Food industries and governments emphasize using modern food preservation and stabilization tools to increase the shelf life of edible products, both of which reduce wastage and cause less stress on the production system. These objectives, as achieved by managing logistics operations skillfully, are a result of enhanced pressure to optimize the distribution of food products to end consumers by upgrading access to infrastructure and implementing transportation methods and managing cold chains to stabilize the supply of food by protecting it from physical and environmental hazards [47].

On the other hand, the PSC describes a network of complex systems responsible for transporting APIs to manufacturers and delivering their finished products to patients. Across all stages and stakeholders, the safety and quality of drug products must be ensured. An effective reverse logistics for outdated and counterfeit drugs is vital to saving patients' lives [48]. A drug not up to standard poses a far greater threat to public health than a food product because any changes to drug ingredients can have fatal consequences. This section explores how food quality and drug safety contribute to public health and the associated

issues. Several food quality and drug safety issues are addressed in this article, including those that follow.

3.1. Counterfeiting/Adulteration

Foods

Counterfeiting/adulteration deliberately degrades food quality by adding or replacing other food ingredients with clandestine alternative elements or removing certain valuable elements. This is generally carried out to decrease the cost or increase the quantity of a food product. Besides being an economic issue, any change to the food will harm public health [49]. For instance, some farm-raised salmon is sold as wild-caught salmon, or inexpensive fish labelled as expensive fish, such as tilapia, is sold as red snapper. Another example is the addition of inexpensive ingredients such as grain, pink slime (a meat product) in ground beef, and counterfeit milk with melamine, which caused renal problems for 900 American babies, six of whom died. Several food types are considered counterfeit [50], including:

1. Food prepared with expired ingredients. Many manufacturers use outdated components to escape the loss, which poses a serious threat to human health as was observed in Pakistan, where expired white flour was used in making pasta.
2. Selling cheaper food at the same price as expensive food and fake labelling and packaging. For example, selling soya oil as extra virgin olive oil after being dyed.
3. The use of unauthorized additives such as preservatives, sweeteners, or dyes.
4. Marketing non-organic goods as organic products. For example, mixing milk with vegetable oil to produce high-fat cheese. The production of artificial honey uses sugar syrups, vitamin C, and different enzymes that are not following the quality required by law.
5. Products are being imported and sold as homegrown. For instance, strawberries and cherries are marketed in March and April as being locally produced.

Food adulteration or counterfeiting is primarily driven by economic gain, and it comes in two forms, unintentional and intentional, as illustrated in Figure 3. The consequences of food counterfeiting are monetary loss to the consumers and life-threatening to the public [51]. For counterfeiters, maximizing profit is a primary concern. They do not consider the risks of counterfeit food to public health. Another major cause of food counterfeiting is the increasing price in the international market and the substituting of specific components or even the entire product by producers and distributors. The substitution of food substances for economic gain is known as Economically Motivated Adulteration (EMA) of food, in which the original food substances are replaced with cheaper ones, another cause of food counterfeiting [52]. As a result of a lack of resources and inadequacies in government regulations and laws, fake labels are produced, which cause customer fraud. Mislabelling is also a part of food adulteration in which any local product is labelled to make it an original or imported staple. For instance, some products do not contain genuine food ingredients as mentioned on their label but have been copied from an expensive food product to increase the profit by fraud. An analysis of DNA data has confirmed that about 30% of mislabelled products come from southern Europe.

Food from animal sources and fresh vegetables have been consumed more widely because of ever-increasing incomes and urbanization; however, urban food markets have faced many challenges in providing consumers with safe and affordable perishable food items [53]. Food items contaminated with other ingredients have been documented in recent outbreaks. They are challenging to identify because they represent a small portion of food-related illnesses [54]. Perishable foods such as fresh red meat that are not correctly preserved after processing can spoil or become contaminated and are a major cause of food poisoning. To prevent food-related diseases, fresh beef must be processed hygienically to avoid contamination with the external origin in the distribution chain of trading markets. The perishable nature of the food supply to the consumer should not be underestimated and must be managed to prevent food-related diseases. Such prevention can only be

achieved through training employees of these departments and implementing it. Qualified staff should be hired to resolve quality-related issues in food effectively. Good hygiene practices should be organized for all FSC stakeholders and sectors [55].

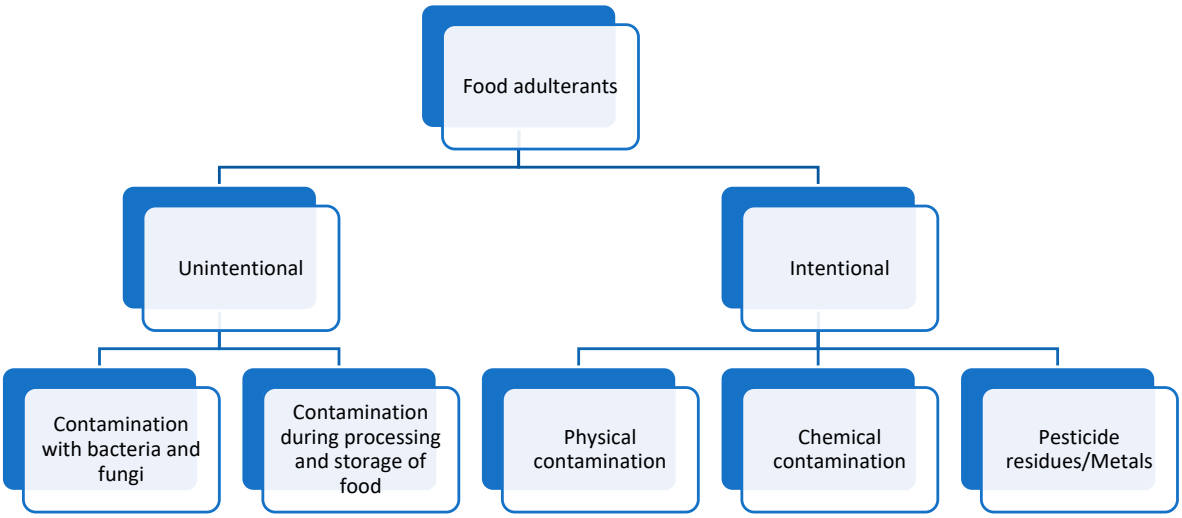

Figure 3. Types of food adulteration.

Drugs

Argiyantari et al. [56] discussed how medications and drugs play a vital role in public health and how to eradicate counterfeit drugs from the authentic PSC to deliver safe, effective drugs to the general public worldwide. Counterfeit drugs are non-authentic medicines produced by using incorrect ingredients in inappropriate quantities to reduce or counteract the potency of the medication and increase financial gain. The addition of harmful substances is also an example of a drug that may negatively impact public health. False packaging and labelling are used to supply these drugs, indicating that they contain ingredients not listed on the label. Falsified drugs are a leading cause of drug resistance and are the most frequent cause of death due to their adverse effects on public health and safety. Both developed and developing countries suffer from the neglect of public health by multi-billion dollar industries.

Globally, counterfeit drugs are being used at an alarming rate, partly due to their availability in different countries worldwide. The WHO reports that counterfeit medicines make up 50% of the global drug market. The main reason for this is a lack of appropriate regulation and implementation and an increase in the number of drug sources. In Asia and Africa, 60% of the anti-infective drugs (antibiotics, anti-tuberculosis, anti-malarial, and anti-retroviral) are out of their pharmacopeial limits, increasing the chances of drug resistance to public health-threatening situations in developing countries. In Burma, Cameroon, Vietnam, Cote d'Ivoire, and Nigeria, 8–35% of infective products were reported as counterfeit or without an active ingredient [57]. Around 77% of oral dosage forms are counterfeited, including tablets, syrups, and capsules, and 17% of injectables are available as counterfeited due to the complexity of the availability of the equipment for the production of injectables. As an example of this issue, A 21-year-old sister of Dr Dora Nkem Akunyili (Professor of Pharmacology, Nigeria) died from diabetes caused by fake insulin used for her treatment in 1988 [58].

The impact of counterfeit drugs on the public is not only medical but also economical. According to the WHO, counterfeit drugs can lead to socio-economic effects such as loss of productive capacity, loss of income, a lack of social well-being, increased poverty, wastage of resources, a lack of confidence, increased mortality rates, increased disease prevalence, and antibiotic resistance [59]. Consumers are increasingly concerned about drug safety, resulting in a significant drop in patients' trust and adherence. Drug counterfeiting results

from various ingredient-dependent scenarios that cause patients to experience multiple problems. These scenarios include [48]:

1. Drugs without the correct amount of active ingredients do not provide any therapeutic benefit to the patient and worsen their condition. An example is the development of antibiotic resistance due to counterfeit antibiotic therapy.
2. A patient's health can also be affected by drugs with fake ingredients or incorrect concentrations or doses for some ingredients. For example, a botulinum toxin, A (Botox), was more concentrated than the real version when given to a physician, resulting in respiratory paralysis and mortality for both the patient and the physician.
3. Drugs with completely wrong and counterfeit ingredients can also contain harmful substances such as floor wax, boric acid, powdered cement, or other harmful chemicals. For example, counterfeit cough syrups with antifreeze chemicals such as ethylene glycol have caused more than 500 deaths among children worldwide. Erythropoietin is another example of a counterfeit IV drug diluted with contaminated water and directly injected into cancer patients. Drug products containing incorrect medications cause several issues. Anti-obesity medicine orlistat (Alli) by GSK was distributed in the United States, containing sibutramine instead of orlistat, which may interact negatively with other medications taken by patients and cause a negative reaction in their bodies.

As a result of these scenarios, patients lose trust in authentic drug products and turn to undesirable alternative therapies. The easy availability and manufacturing of counterfeit medications contribute to their success. As a result of a lack of rules and regulations, fake drugs have a high-profit margin and distributors have a low risk of being caught. Counterfeit medicines are readily available online because of the rising prices of original drugs and the high consumer demand. In addition, because the public lacks knowledge of drug products, pharmacies, hospitals, and companies can be trusted without a problem [60]. Several factors facilitate the existence of counterfeiting medicines, and the government should identify these factors so that accurate regulation can prevent counterfeiting. These include:

1. A lack of constitutional protection.
2. A failure to enforce the existing constitution.
3. Insufficient national drug regulations.
4. Ineffective punishment.
5. Corruption.
6. Excessive demand over supply.
7. Inadequate coordination between stakeholders.
8. Absence of regulation by exporting countries.

3.2. Genetically Modified (GMO)

Foods

Governments around the globe have established a variety of approaches to address the long-standing food crisis. GMO meat products from hormonally treated animals have gained improved interest, presenting serious health consequences to consumers. Meat adulteration by mixing meat from different animal species and ractopamine residues (RAC) in imported and local food products was also detected using quantitative and qualitative methods. It is considered one of the leading food adulteration technologies and illegal additives that involve inserting foreign genes from bacteria, animals, viruses, or other plant species into the consumed food [61,62].

Meat products have numerous nutritional quantities and are recommended for daily usage, although meat's nutrients and mineral deposits fluctuate according to components, composition, and manufacturing conditions. Finally, high-quality meat should be available with all nutritional values and without impurities or unknown species. Due to high consumption and over-priced meat, producers tend to use unlicensed species in producing

processed and unprocessed meat products. Meat adulteration, which involves mixing bovine meat with meat from other animals such as pork, donkey, chicken, horse, sheep, and dog, is a general practice in several countries to increase the quantity and sell value [63,64].

Drugs

GMOs have appeared as one of the mainstays of biomedical research since the 1980s. For example, GMO versions of human genetic disorders enabled scientists to test novel treatments and discover the roles of candidate risk factors and transformers of disease outcomes. GMO animals, plants, and microbes also modernized the production of complicated drugs by enabling the generation of cheaper and safer therapeutics and vaccines [65,66]. Pharmaceutical drugs range from the recombinant vaccine of Hepatitis B (HBV) produced by GM baker's yeast to injectable insulin produced in GMO bacteria Escherichia coli and to factor VIII (for haemophiliacs) and tissue plasminogen activator (TPA, for heart attack or stroke patients), both of which are produced in the GMO mammalian cells grown in artificial culture. These pharmaceutical products are very sensitive and cannot bear any environmental stress, radiation exposure, and random rupturing during the transportation and logistics of drugs. So, a more careful analysis is required to manage these products in underdeveloped and developing countries, while developed countries have implemented special technologies to handle such pharmaceutical products [67,68]. Due to the sophisticated handling issues, a more trained and skillful management team and a blend of modern tools are required for the efficient management and safety of PSCs worldwide.

3.3. Microbial Contamination

Foods

Microbial contamination occurs when food products have been contaminated by microorganisms such as mold, bacteria, toxins, viruses, and fungi. Contamination can occur through several means; for example, undercooking chicken can produce a bacteria, campylobacter. During the slaughtering and rearing of animals, salmonella that lives in the intestines of animals can transfer onto the food products. Preparing and storing high-risk raw foods very close to being ready to eat can lead to cross-contamination [69,70]. Some fish and shellfish could eat toxic organisms that are hazardous to humans if they consume them. All the issues mentioned above cause food contamination at each phase of FSCs. However, most issues arise in the manufacturing of edible products and during improper warehousing where the storage conditions are violated by any human error, environmental issue, or any deficiency in the infrastructure of FSCs and logistics operation while transporting food from the manufacturer to the customer. So, supplying food having any microbial agent causes different diseases and death in some cases [71,72].

Drugs

Microbial contamination of drugs has proved an everlasting challenge for researchers and pharmaceutical manufacturers around the globe. It could result in spoilage of a formula by catabolism of active components and excipients by affecting its potency, efficacy, and stability. A high number of microbes presents a serious health risk to consumers, especially those who are already ill or in a health-weakened condition. Numerous cases of infections due to the contaminated drugs were previously reported. Some common drug contaminants include bacteria, where contamination with Gram-positive bacteria implicates human intervention as a major reason for product contamination, while the presence of Gram-negative bacteria suggests a lack of process control in pharmaceutical environments, especially involving water systems and raw materials. Gram-negative rods are considered the most commonly found bacterial quarantine in non-sterile pharmaceuticals, regardless of geographical location [73]. Contamination of these kinds may occur during the customer's manufacturing, labelling, packaging, and utilization. The presence of active ingredients in the drug causes severe reactions in the patients and certainly causes death [74,75].

3.4. Environmental Issues

Foods

Some environmental factors such as temperature, high pressure, radiation exposure, UV sunlight, and high moisture contents of air are the factors responsible for deteriorating the quality of food as they can change the colour, texture, taste and flavour of the food without having any serious reaction, but the food is denatured because of the presence of any enzymatic or chemical induction cascade [76,77]. Foods containing carbohydrates including dairy products and proteins such as meat products are easily denatured by heat stress. So, denatured products have a bitter taste and should not be consumed, but if someone eats them, this will cause severe health issues such as food poisoning, which can lead to a gastrointestinal (GIT) tract infection or severe dehydration that could cause death [78,79]. Radiation exposure is another risk for food products that can denature the food; thus, its active ingredients can be changed and cause a serious threat to health if consumed by any human. Radiation breaks the bonds between the food residues; thus, stability is lost before the actual utilization of products. Another factor is the high moisture content in rainy seasons, which denatures the integrity of ingredients in dry foods such as flour, snacks, and pulses [80,81].

Drugs

It has been observed that certain environmental stress factors are responsible for the degradation of active ingredients of drugs at any stage of the PSC or during logistics operations. Temperature is a key factor responsible for the denaturation of drugs. Due to denaturation, patients face certain health as well as economic losses such as with various hormones as insulin requires a storage temperature for its integrity during its movement through the supply chain and therefore loses its effective temperature and its intra-chemical binds break and thus have no effect when administered into the patients [82,83]. The other factor is radiation exposure, which degrades various drugs when a very high UV light falls on them. Improper storage in warehousing or during logistics denatures the drug's chemical formula due to any damage to its packing material or substandard packaging of the drugs. Other uncontrollable external influences could also affect the environmental condition of drugs, such as natural disasters [84], climate disturbances [85], terrorism, or political issues, such as wars or sanctions imposed on certain countries [86]. All of these can delay the delivery of drugs from manufacturer to retailer, cause degradation, or allow the mixing of fake drugs into the original authentic ones. For example, at the beginning of the COVID-19 crisis, unexpected conditions strained the world and caused disturbances to all supply chains, including the PSC [87,88].

3.5. Biochemical Contamination

Foods

Biochemical contamination refers to the presence of any bioactive compounds in food that can react either by catabolism or anabolism and produce a toxin or allergen that can react upon eating with any living organisms, normal body tissue, chemical compound, enzyme, and hormone, and even with any organ. Allergenic contamination happens when a food product that causes allergic reactions comes into contact with other food products [89,90], for example, if the same knife used to cut normal bread is then used to cut gluten-free bread, or if pasta is stored in a tub that contains peanuts. Moreover, cow's milk allergies are very common among children and infants. They usually appear in the first six months of life. Fresh cow's milk and products made with milk, such as cream, yoghurt, cheese and butter, and milk powder can trigger a milk allergy. Milk allergies are common among people who have asthma as well. Lactose intolerance is a reaction to the sugar in cow's and breast milk but is different from a milk allergy. The allergy to cereals containing gluten is also known as wheat allergy. Foods with wheat, rye, barley, and oats can cause it. Many people have intolerances to wheat rather than allergies, but allergies are also common. Coeliac disease is different from gluten sensitivity. Gluten causes this

gastrointestinal condition, which, if unmanaged, can lead to long-term complications. For someone having a food allergy, utilizing even a small quantity of that food is sufficient to cause a deadly reaction. Finally, it is essential to prevent allergenic contamination of food in the home [91,92].

3.6. Emergence of New Technologies

Drugs

New technologies in PSCs have revolutionized manufacturing, processing, packaging, and logistics. However, certain problems arise in different phases of the PSC, such as distribution and point-of-sale, which can affect the safety of delivered drugs. These issues vary but solving them faces barriers such as the high costs required for a first-time investment to integrate these technologies and time required to adapt to the change, lack of implementation of strict regulations, inefficient coordination, and collaboration across phases and stakeholders of the PSC, the challenge in openness and sharing the information, lack of objective yardsticks, and lack of patients' awareness. Implementation of emerging technologies causes other challenges to manage the PSCs due to little training and workforce expertise and having complex operational cascades to the staff who have limited knowledge of conventional technologies and does not have sufficient knowledge to manage the emerging technologies such as traceability and forensic technologies [93,94]. These can affect the good side of implementing these sophisticated technologies to achieve safe drugs. An effective PSC that implements a successful technology depends mainly upon collaboration and coordination between the stakeholders, including patient participation, keeping them up to date and providing them with the training if required [95]. Stakeholders also require proper training in PSC to manage and resolve hazards during a natural disaster [5].

3.7. Lack of Consumers/Patients' Awareness

Foods

Eating hygienic food is a basic right of every individual, and people expect that the food they eat will be hygienically and safe. Most food denaturation occurs during storage and transportation, which becomes an issue due to consumers' lack of knowledge of proper handling [96,97]. Inform consumers about food handling to reduce waste and food-borne illnesses is a significant problem. For example, a study conducted in Germany said that 35% of foodborne illnesses were due to the lack of proper handling and storage of information on the consumer's side. These illnesses caused people to face economic and health issues and burdened the country's healthcare system [98]. The awareness of consumer and their knowledge regarding the importance of food quality and proper storage are considered significant for ensuring consumer safety in the social marketing of edible products. Product labels present information about the proper storage and handling of any food product. However, about 70% of consumers do not pay attention to these labels, and 20% do not consider this information significant to educate them to maintain food quality and nutritional values [99,100].

Drugs

Every patient expects to have an effective medication which can cure him immediately. Pharmaceutical products have some bioactive compounds that require proper handling and storage conditions for proper functioning and to prevent denaturation and oxidation-reduction reactions [101,102]. Patients already in depressed conditions due to bad health do not consider the instructions on the labels of these medicines, which provide necessary storage and handling information about these medications. Ignorance of this critical information will result in the denaturation of the bioactive components of drugs. Thus, these drugs will not function as they should and eventually negatively affect patients. A lack of patients' awareness of storing and handling expensive medications such as hormones can easily denature and burden the production and health systems [103,104]. Online pharmacies often sell and deliver medication to patients without requiring prescriptions,

a serious issue because no mechanism exists to check and balance the medication they provide. Moreover, customers are unfamiliar with the processes by which they could detect fake drugs unsuitable for human use [17,105].

4. Solutions for Food Quality and Drug Safety

Food quality and drug safety issues are the chief public health concerns nowadays around the globe. Policymakers, governments, and other stakeholders are trying to find and implement solutions that can effectively address all the issues in these two critical fields. This segment will discuss similar solutions to integrate and overcome both public health issues integrally, as illustrated in Figure 4. The solutions are classified into four main points: tools, design, technologies, and resource management.

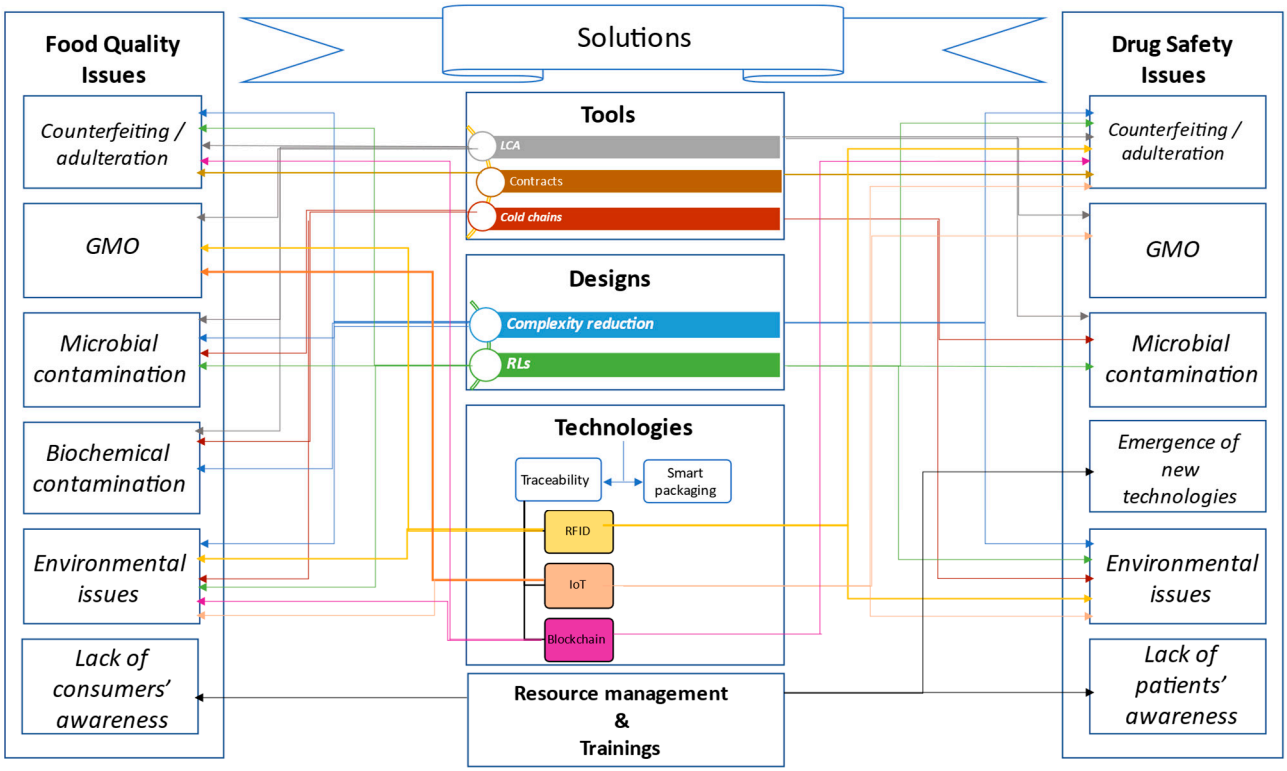

Figure 4. Integrated framework for solving issues of food quality & drug safety.

4.1. Tools

4.1.1. Life Cycle Assessment (LCA)

LCA is a process aiming to determine a product's environmental impacts throughout its lifespan. It is a useful tool for evaluating critical products such as foods and drugs; this process is highly recommended [106]. LCA can demonstrate, for example, that switching to a slurry system for manure management will reduce ammonia and nitrate emissions, reducing the impact of beef production on acidification and eutrophication [107]. Product sustainability can be ensured by considering LCA at various stages in the supply chain, beginning with raw material production and extraction, moving onto manufacturing, and then packaging, distribution, retail, use, and disposal [108]. Such assessments also evaluate the preservation of nutritional value and the denaturation of their bio-active contents. Experts in food operations management and pharmaceutical bio-active metabolism can evaluate all these factors to get a sense of the shelf life of the food or drug product to ensure that it will not be destroyed by biochemical reactions or microbiological infections at any stage of its life [88,109]. As a result of this knowledge and understanding, the organization can deliver safe food and medicine to its customers and avoid loss by preserving the

products; this generates revenues for the business because shortages are a major concern around the globe [110,111].

According to Figure 4, maintaining the LCA of food and drug products to resolve various issues was effective. LCA can be used to solve food quality issues such as detecting food adulteration [112,113], GMO foods [114,115], microbial contamination [116,117], and biochemical contamination [118,119]. LCA can also be used to solve drug safety issues to detect if there is drug counterfeiting [120,121], GMO drugs [122,123], and microbial contamination [124,125].

4.1.2. Contracts

Contracts are strategic management approaches that sellers and buyers use to manage supplier and customer expectations, relationships, costs, and risks. These contribute to the success of the organization in a broader sense. Within supply chains, information asymmetry always persists between consumers and stakeholders. A lack of regulations and standardization, combined with legacy systems, exacerbates the issue [126]. Contacts with third parties create a link bonded legally between producers and consumers. Contacting parties must know every detail of their products, from the extraction and receiving of raw materials to manufacturing procedures within the industry, up to the level where the consumer receives the final product, so they understand what they are selling. Thus, there will not be a risk of data manipulation or theft due to a lack of security in the future [127].

According to Figure 4, setting contracts between the stakeholders of food and drug supply chains can solve issues regarding trust and, therefore, ensure the source of food supplied is trustworthy, food is high quality, and no chance exists for adulteration [128,129]. Contracts can also solve drug safety issues such as counterfeiting, especially if the contracts were signed with trusted parties to ensure the supplies of APIs [27,130].

4.1.3. Cold Chains

Cold Chain Management (CCM) is a complex and important process required for perishable goods in the food and drugs sectors. A "cold chain" preserves perishable products from production to the final consumption stage at low temperatures. All perishable food products such as vegetables, meat, and bread, and some perishable drugs such as hormones and vaccines can easily be degraded by a minor change in their temperature, so cold chains in logistics operation safeguards the quality and safety of these products. Special vehicles with temperature-controlled refrigerators are utilized for logistics that are necessary for maintaining the internal temperature to keep the products safer from the harms of temperature fluctuation in the external environment, especially during summer. Smart sensors are also attached to the products through a USB known as a temperature data logger that can read the product temperature in real time and provide alarms if the product is out of its temperature safety zone throughout its journey. Cold chains also protect the goods from microbiological destructions during transportation at large distances. As a result, customers receive quality food with integrity in taste and nutritional value and drugs with all the bioactive components necessary for the safety of patients to whom it will be administered [131,132].

As an example of the potential similarities, using temperatures as a critical control point, Figure 5 compares the similarities of the processes of both FSC and PSC. While other factors, such as pressure, radiation exposure, environmental changes, and other microbiological hazards, may have impacts, these are not common and rarely occur. Therefore, we have shown how we can use a cold chain as a solution for both supply chains during the transportation of either food or drug products.

According to Figure 4, the cold chain's processes and its tools can solve food quality issues such as environmental issues [133,134], microbial contamination [81,135], and biochemical contamination [136]. Cold chains can solve drug safety issues such as environmental issues [137,138] and microbial contamination [139,140].

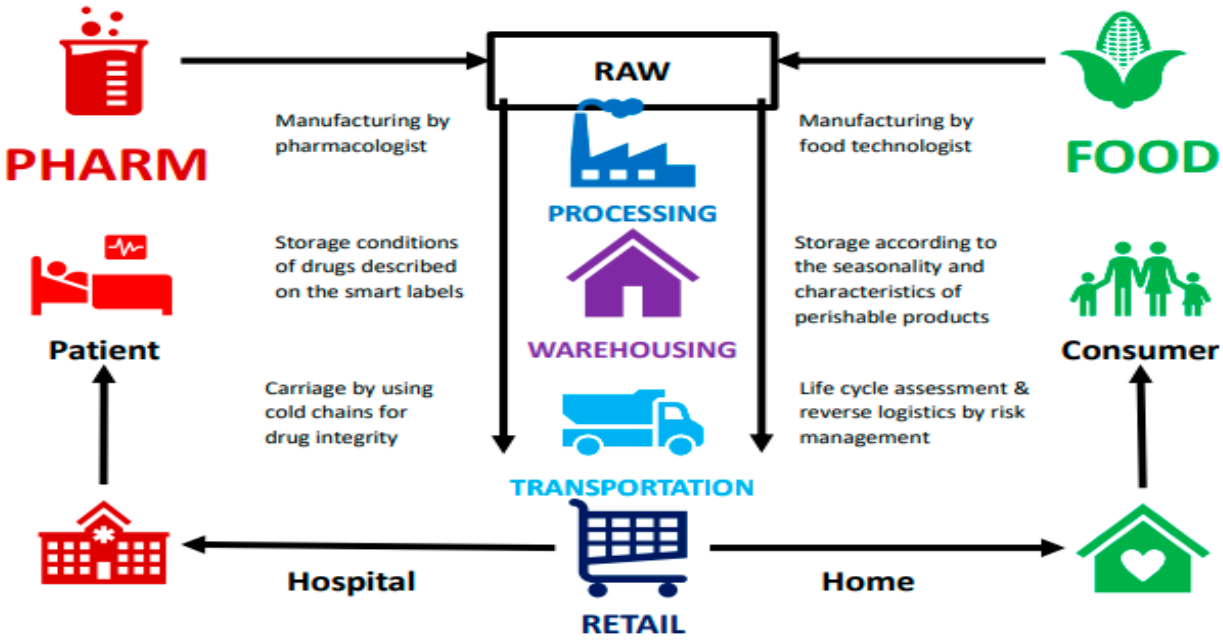

Figure 5. Similarities between FSC & PSC and cold chain importance.

4.2. Design

4.2.1. Complexity Reduction

The design of the supply chains is an important factor to consider and review regularly to achieve efficient and effective results, which in turn achieve safe products. Complexity reduction in supply chain design applies to both FSCs and PSCs. During the unprecedented COVID-19 crisis, the long supply chain operation and the complex logistics caused a delay in the delivery of perishable food and drugs, thus causing these important products to denature. As a result of the complexity of FSCs and efforts to reduce food wastage during its manufacturing, processing, storage, and distribution to end consumers, direct or short FSCs have been widely embraced in many developed countries [141]. Some have observed that consumers in some societies preferred to buy items directly from the producers or farms to avoid denaturation during the time-consuming product distribution process from the manufacturer to the retailer and to better understand the customer's expectations [142]. Despite their multiple advantages, there are no specific models to ensure the food safety of local or short supply chains. This is a matter of concern for policymakers and manufacturers, who must develop a system for transporting food from farm to table for end consumers without intermediaries [143]. Short FSCs are environmentally friendly because they do not require packaging or storage of the final product, eliminating the need for biodegradable or non-biodegradable packaging materials. A prepared product is immediately handed over to the consumer, so there are few chances for degradation by biochemical or microbiological agents. This contributes to society's health and well-being and enhances harmony among the local population when they exchange their products [144]. Figure 6 illustrates the benefits of having short FSCs.

Complexity reduction in the case of the PSCs can resolve other issues, most importantly detecting drug counterfeiting. Recent reports indicate that the increase in counterfeit drugs results from unnecessary intermediaries between the manufacturing stage and sales of drugs. As a result, some stakeholders mix up fake and original drugs due to their lack of knowledge and unawareness of counterfeit drugs' hazards and side effects. Therefore, working on complexity reduction of distribution hierarchy, for example, is essential to eliminate the introduction of counterfeit drugs because it will simplify the network and make it easier to monitor and trace [145]. Streamlining and simplifying the distribution network of PSCs, as illustrated in Figure 7, without cutting necessary procedures, is necessary in the first place to eradicate counterfeit drugs. There is a need

to closely coordinate the manufacturing and sales departments by eliminating the need for warehousing and distribution if not needed. This will also make companies more cost-efficient and force companies to work toward demand-based production, preventing the risks associated with storage and ensuring drug quality and ingredient conservation.

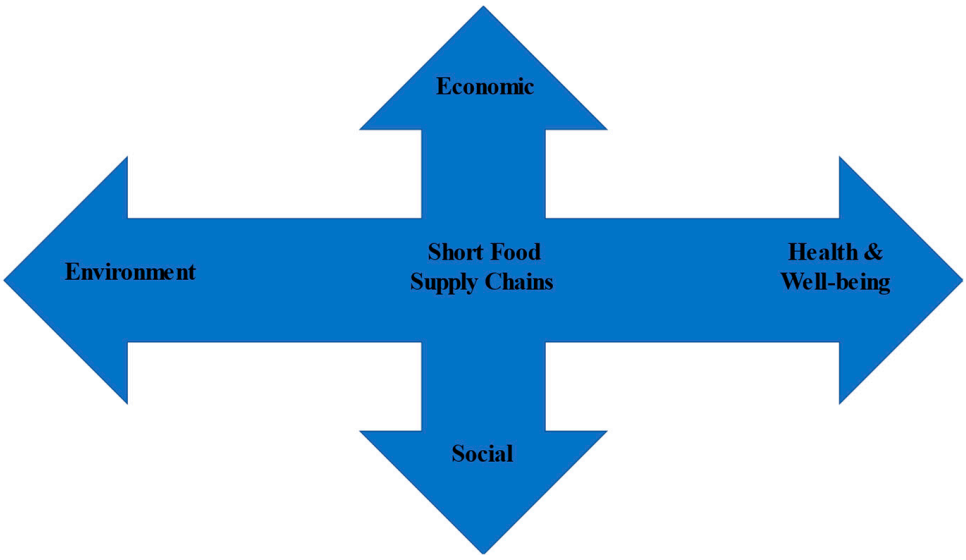

Figure 6. Benefits of short FSCs.

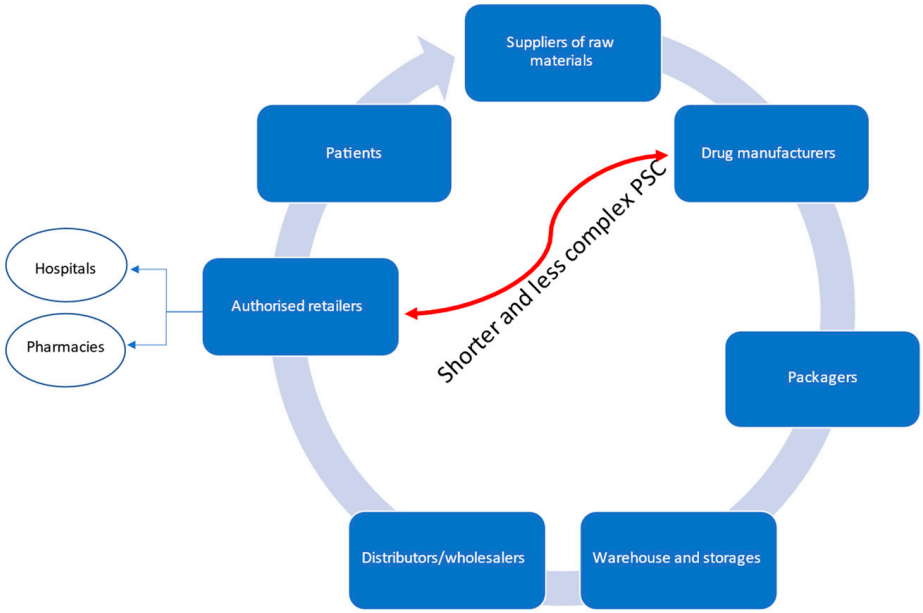

Figure 7. Simplify the networks for PSCs. Source: Balas et al. [146].

According to Figure 4, complexity reduction can solve food quality issues such as adulteration, microbial and biochemical contamination [147,148], and other environmental issues [24,41]. It can also solve drug safety challenges, such as environmental issues [95,149], and greatly contribute to resolving issues related to drug counterfeiting [150,151].

4.2.2. Reverse Logistics (RLs)

In the past two decades, researchers have increasingly focused on RLs because a large amount of waste was generated in distinct phases of FSCs and PSCs due to manufacturers' defaults in production or delays caused in transportation and not delivering the products to consumers at the right time [93]. The recall of food and drug products has been experienced in all stages of their supply chains. Denatured products are returned to their manufacturer

or disposed of in case they are counterfeited. It is the manufacturer's responsibility to evaluate the contents for recycling if possible. Otherwise, it is discarded [152]. RLs play a significant role as eco-friendly procedures and one means for closing the loop of a typical forward supply chain [153] that can ensure food quality and drug safety consumed by end-users. Discarding food or drug products and taking them through a proper disposal path of the main supply chain will ensure high public health safety and quality of the consumed products. There are major side effects to consuming denatured products containing bacteria and fungi, which could severely harm human health and strain health systems already under intense stress due to various complications. It is also possible to suffer fatal consequences from consuming products outside their standard level, depending on the situation. Hence, efficient RLs guarantee the health and safety of the population around the globe [154,155].

According to Figure 4, the RLs can solve food quality issues such as adulteration and microbial contamination [156,157] and environmental issues [152,158,159]. They can also solve drug safety issues such as counterfeit and microbial contamination [160,161] and environmental issues [162,163].

4.3. Technologies

4.3.1. Anti-Counterfeiting Technologies

Although the quality and safety of both FSCs and PSCs are critical to achieving public health, PSCs are more serious. As a preventive measure for protecting public health and patient safety, it is crucial to adapt and utilize an effective anti-counterfeiting technology. Government authorities can use these technologies to evaluate the safety of PSC. For example, the 1987 US Prescription Drug Marketing Act clearly stated that wholesalers should furnish the pedigree before every supply. The following technologies can combat counterfeiting [48]:

- Overt anti-counterfeiting technologies (OACTS):

This technology is used in drug packaging. This way, counterfeiters cannot make copies of the drug packaging and can be easily identified by patients. This feature is simple and cost-effective. Many pharmaceutical companies use this technology to prevent counterfeit drugs. One example is the use of holograms.

- Covert anti-counterfeiting technologies:

A transparent fingerprinting technique for tablets uses embedded images and digital watermarks. It is simple, cost-effective, and does not require regulatory approval but only has a limited range.

- Forensic anti-counterfeiting technologies:

In this process, chemical, biological, and micro taggants are used. The technique is secure and cannot be copied. Still, it is expensive and limited in use because it requires a licensing system.

- Traceability technologies:

Different technologies can be used to track and trace items and identify counterfeits, including but not limited to barcodes, pedigrees, mass serialization, radio frequency identification (RFID), IOT, and the blockchain (an emerging technology). These technologies apply to foods and drugs:

1. RFID

The technology uses radio waves and wireless capabilities to transmit digital information using microchips containing tags. Many items and products can be verified using these tags while reducing the burden of maintaining supply chain integrity. Customers can check the authenticity of food or drug products at all points of the supply chain, benefiting both the consumers and the supply chain partners to ensure the food quality and drug safety delivered [48]. According to Figure 4, RFID can solve food quality issues such as

environmental issues [164,165] and GMO food products [166,167] and can solve drug safety issues such as unintentional counterfeiting due to random errors [168,169], intentional counterfeiting due to human objectives [170,171], and environmental issues [172,173].

2. IOT

IOT is a collection of networks of physical devices that can be attached to food or drug products and are connected over the internet. These devices are numerically integrated with sensors, software, and other technologies to track and measure supply chain visibility, interactions, agility, and data exchanges to control, plan, and organize their processes. Many FSC and PSC entities have used this technology for easy traceability and automatic processing [174]. Research has categorized IOT as an emerging tool despite its many advantages due to difficulties arising from its implementation in supply chains. IOT technologies face many challenges, including a lack of network structure, hardware technical skills, integration, and interoperability, internet accessibility, and big data management. Researchers have predicted that sufficient infrastructure will be established soon, increasing the potential of IOT in supply chains [21] to ensure food quality and drug safety. According to Figure 4, IOT can solve food quality issues such as environmental issues [175,176] and GMO food products [177], can solve drug safety issues such as GMO drugs [178,179], environmental issues [180,181], and contribute to detecting drug counterfeiting [182,183].

3. Blockchain

Blockchain provides food and drug companies with security, traceability, and decentralizing data related to their products. Blockchain technology is an electronic ledger that follows a decentralized network model. In this technology, information is distributed across all nodes in the network rather than gathered into one database. Verified information is added to the previous block's hash value and is hashed to produce a new block using a cryptographic hash function. Immutability is a unique feature of this platform since every change is recorded, displayed, and tracked to the whole network of collaborators with access to the data. The information is also decentralized across several servers [184]. Blockchain technology effectively prevents food and drug counterfeiting and cyberattacks [49]. Different organizations are utilizing technology to manage the integrity of their supply chains through developing prototypes and simulation modelling. The IEEE Standards Association has organized a series of workshops and seminars to evaluate the effectiveness of blockchain technology by comparing it with other systems to ensure the safety of food and drugs in supply chains. Drug manufacturers are now using this technology to ensure the quality of pharma products across supply chains [185].

Despite all these benefits, blockchain technology has faced challenges in supply chains where trust remains an issue between stakeholders, although every data transaction in a blockchain is recorded so that it cannot be hacked or corrupted by any stakeholder to cheat others. In addition, it is very expensive to invest in implementing the technology for the first time due to required maintenance after regular intervals, managing servers, and avoiding bugs, resulting in an increase in price and an inability to beat competitors in the market, consequently a decline in revenue [186]. Furthermore, this technology will require well-trained personnel to ensure the correct use of data and therefore ensure high-quality returns. According to Figure 4, blockchain can solve food quality issues such as food adulteration, especially if the source of supply is known [129,187], and environmental issues [188,189]. For drug safety issues, blockchain can mainly trace and detect counterfeiting drugs [27,190].

4.3.2. Smart Packaging

The intelligent and smart packaging of food and drugs enables them to face certain environmental stresses as it blocks high-energy UV radiation, which safeguards the integrity of products by maintaining their chemical bonds [191]. Moreover, efficient packaging material did not allow the entry of tiny creatures such as viruses, bacteria, and fungi responsible for the microbiological destruction of food and drugs. Packaging also maintains the moisture content of the products and prevents them from damage due to which

texture, colour, and flavour of the food remain intact. Sometimes moisture from the environment damages substandard packaging and reacts with the bioactive ingredients of drugs, changing their chemical formula and becoming effective, especially during the rainy season. Manufacturers also realized that smart packaging materials are necessary to deliver safer food and drugs to the customers to seek their trust in their brand [192,193].

According to Figure 4, smart packaging can solve food quality issues such as adulteration and microbial contamination [194,195], biochemical contamination [196,197], and environmental issues [198,199] and can solve drug safety issues such as counterfeiting drugs [200,201], environmental issues [202,203], and microbial contamination [204,205].

4.4. Resource Management and Training

Scientists and researchers are implementing food quality and drug safety tools to prevent public health issues. As an example of food processing, scientists are researching novel extraction tools, fermentation for natural preservation, personalized nutrition based on individual caloric requirements, advanced forward osmosis separation techniques and setting up food banks in developed countries to salvage and redistribute nutritious food to vulnerable groups [113]. Moreover, reducing food wastage and ensuring sustainability can be achieved with better logistics operations management, generating revenue without using expensive technology. With such a crisis and unprecedented conditions like COVID-19, specialized skills and effective management in logistics could prevent food or drug products from denaturing and their contents from deteriorating. They will also be able to ensure the products' authenticity and eliminate counterfeits. To address the hazards to products during transportation, logistics staff should have modern training so that valuable products could be saved from environmental hazards, for example, in specific instances. Science always tries to provide technical solutions to achieve high food quality and drug safety. Still, it is the responsibility of the stakeholders to make use of these sources by training manpower that is mentored enough to get the most out of the technological solution by smart and efficient management.

Skilled staff and experts should receive purpose-oriented learning opportunities at their jobs to increase their awareness of food and drug processing mechanisms and familiarize them with supply chain management standards during an outbreak or other unprecedented situations. Around the world, certain universities provide purpose-oriented weekend programs for employees, such as MBA hospitals and healthcare management programs. This training enables staff to understand and use modern technology and effective planning to address drug safety issues in supply chain and logistics operations. Specially designed curriculum for utilizing modern tools to ensure better public health facilities must be developed because skilled staff must have a holistic knowledge of drug safety and food quality factors. Weekend classes accommodate working professionals, making this a truly dynamic and accessible program. A blended learning approach of online and on-campus sessions exposes students to the new realities of the business world, and it reinforces student-centred learning by providing a truly transformative and interactive experience. Blended learning techniques throughout the MS studies will be presented with a diversity of instructional approaches, learning technologies, case studies, readings, role plays, and industry engagements.

Researchers suggest that companies develop effective procedures for supply chains to cope with disruptions or unplanned events. Their research suggests that supply chain and logistics staff training in food and pharmaceutical companies must be based on present conditions as the best example of how to train staff using modern technology to overcome these disruptions. Figure 8 illustrates the correlation between staff training and the need to understand and run the technologies safely and efficiently and achieve a resilient supply chain.

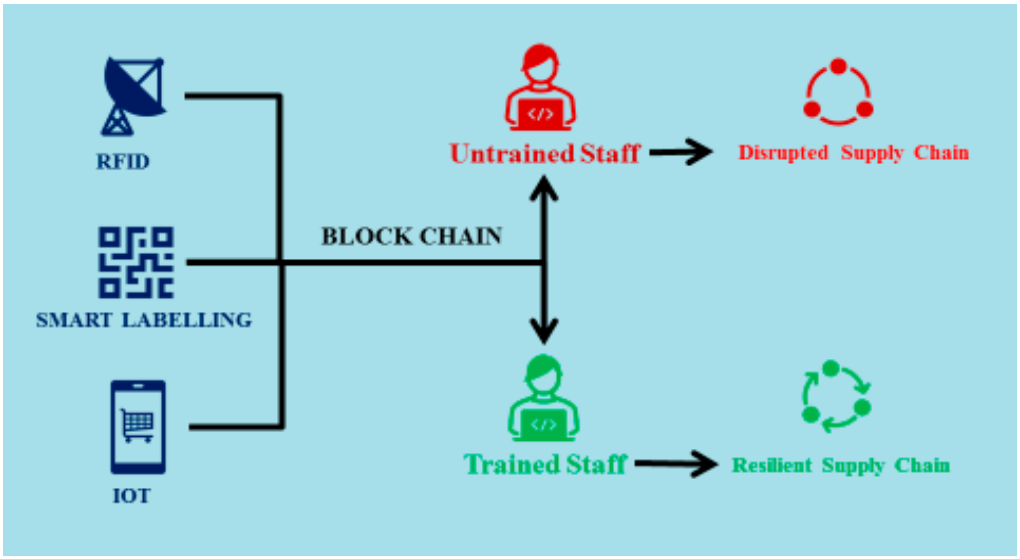

Figure 8. Correlation between implementing technologies and staff training.

5. Overall Review Findings

This paper explores the main aspects of achieving efficient FSC and PSC management, as well as the crucial role that food quality and drug safety play in ensuring public health and meeting the increasing demand of the global population at high standards. Scholars, researchers, and government policymakers agree that the issue of food quality and drug safety is incredibly complex, and no single solution can guarantee to provide flawless products. Consequently, food and drug products are prone to various loopholes that affect their safety, intentionally or unintentionally, and counterfeiters exploit these points to financially grow illegally.

First, the review discussed factors affecting food quality and drug safety and classified them into seven main categories, with counterfeiting or adulteration at the top of the list. The quality of food or safety of drugs is degraded deliberately by substituting main ingredients with clandestine alternatives or removing valuable elements to reduce the cost or increase the quantity of these products. However, this makes food and drugs unfit for human consumption, often harms public health, and causes needless deaths. GMO foods and drugs are also problematic due to their adverse impacts on quality standards and safety, primarily to combat the food and drug crisis due to high consumption and prices. For example, certain meat products are expensive; therefore, producers often mix these products with meat from other animals to increase the amount and value of the product. Several other topics were discussed, such as microbial and biochemical contamination, the development of new technologies, environmental concerns, and the lack of awareness of patients and consumers. Several issues are common to both supply chains, while some are limited to only one of the supply chains.

Second, the objective of the review was to identify possible solutions to overcome these issues and improve results through proper supply chain management. An extensive literature review was conducted to achieve this objective, and similar solutions were found that can be implemented to overcome both food and drug issues. Solutions were categorized into four categories: tools, design, technologies, resource management, and training. Among the solutions included under the tools layer are LCA, contracts, and cold chain tools. A design layer identified solutions such as reducing the complexity of supply chains and RLs. The technology layer examined many technologies used to detect counterfeits, which were primarily categorizing them into two categories: traceability technologies, such as RFID, IOT, and blockchain, and smart packaging technologies. The final category layer emphasizes soft skills, which can be achieved through extensive training and resource management. Training opportunities should be available to employees

working with FSCs and PSCs to better understand the critical nature of the food and drug products they work with and their effect on public health, as well as to learn how to use the technologies and simplify their work. A skilled workforce should be experts in managing critical supply chains, whether under normal circumstances or in unusual situations.

The third objective was achieved by investigating and discussing methods that could be used to resolve similar issues related to FSCs and PSCs, as well as proposing an integrated supply chain framework that ensures the quality, safety, and sustainability of food and drugs through a multilayered cross-verification cascade. This framework has been proposed for similar solutions to overcome both public health issues integrally. Figure 9 summarizes the total number of solutions that can be used to resolve food quality and drug safety issues in an integrated form across both supply chains.

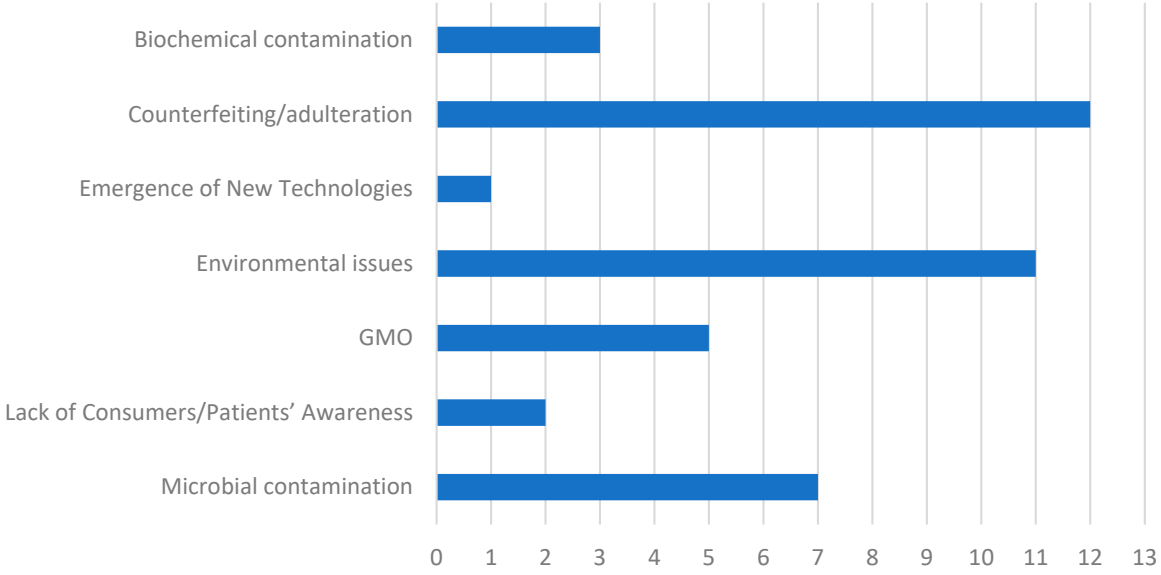

Figure 9. Total number of proposed solutions that can be used to resolve the issues.

As a result of the importance and seriousness of counterfeiting and adulterating food and drugs, much of the current research has focused on this issue on a large scale. According to the analysis, counterfeit/adulteration issues receive more attention because of their high rate of occurrence, which explains why they receive the highest ranking compared to other solutions that have been discussed to mitigate and overcome the concern issue and ensure a high level of quality and safety. This is followed by environmental issues and then microbial contamination, both of which significantly impact food quality and drug safety.

6. Conclusions

From the beginning of the 21st century, researchers and scientists have shown their interest in public health issues, specifically addressing the importance of maintaining the quality of food and the safety of drugs to reduce the burden on global health care systems and ensure the health of communities. Using healthy, high-quality foods and safe drugs helps develop a strong immune system and decrease the impact of a disease. Unfortunately, the quality of food and drug products is deteriorating daily due to various intentional or unintentional environmental factors, and these factors are not limited to a particular phase of a supply chain. Some factors present themselves at the manufacturers' end due to the complex manufacturing processes, some at the warehousing stage, and some during logistics, distribution, or retailing. The quality and integrity of food and drugs can also be compromised while being used, handled, or stored by customers.

This study systematically reviews the literature to identify gaps in the most critical public health topics related to food quality and drug safety research. In addition, the review presents the challenges in supply chains and elucidates the provided solutions.

Many research studies have explored the importance of food quality and drug safety. Nonetheless, to the best of our knowledge, no study has carried out a meta-analysis to examine the factors affecting food quality and compromise drug safety in combination. As such, this review bridges the literature gap by identifying the factors causing issues for both supply chains and classifies similar solutions in supply chain systems through implementing tools, emerging technologies, exploring policies, focusing on critical control points, and redesigning the supply chains to achieve the desired results and improve public health.

Several issues are common to both supply chains, including counterfeiting, genetic modification (GMO), microbial contamination, environmental issues, and lack of consumer/patient awareness. Some issues are more to food, such as biochemical contamination or drugs, such as the emergence of new technologies. A multi-layered cascade in the integrated supply chains has been proposed to overcome both public health issues integrally. The first layer corresponds to the tools category, which includes life cycle assessment (LCA), implementing contracts between suppliers and buyers, and the special tools used for the cold chain processes in logistics operations to assure the basic processing operations and safeguard product quality and safety. The second layer is a modification of the supply chain structure through redesign, which is essential to reduce complexity and improve reverse logistics to avoid certain extra steps that may be responsible for unsafe food and drugs. This process should be reviewed regularly to ensure efficient and effective results. The third layer consists of modern technologies to protect public health and patient safety, such as anti-counterfeiting, traceability, and smart packaging, which can be implemented and deployed to ensure food quality and drug safety and detect the presence of original or fake products at any phase of the supply chain. These three layers assist in achieving an integrated supply chain by leveraging a combination of tools, processes, skills, and technologies to solve the similar issues of PSCs and FSCs within a limited timeframe for maintaining public health and reducing wastage in a world where there is a severe shortage of food and drugs in underdeveloped and developing countries.

The current review can serve as a basis for future research by focusing on the quantitative component and testing hypotheses based on statistical analysis. To provide more comprehensive results related to this topic, surveys and interviews can be conducted with respondents and stakeholders from both supply chains (food and drug) and results can be compared. The proposed framework could also be tested on other topics related to public health to determine its feasibility and provide a path for gradually integrating the multiple layers. Further research should be conducted to compare the solutions discussed in this review. Such research would facilitate updating the proposed framework to curb food quality and drug safety issues.

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