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Review Article

Drugs and Food Anti-counterfeiting Technologies Combating Counterfeiting: A Systematic Review

Mona Haji*

Postdoctoral, College of Science and Engineering, Hamad Bin Khalifa University, Qatar

***Corresponding author:** Mona Haji, Postdoctoral, College of Science and Engineering, Hamad Bin Khalifa University, Qatar

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Abstract

Anti-counterfeiting technologies against drugs and food counterfeiting are the need of the day to fight, prevent, and combat the counterfeiting of products. Numerous studies used different technologies against food and drug counterfeiting; therefore, the current systematic review evaluated those technologies' use, effectiveness, and how they will help combat the counterfeiting of food and drugs. Different online databases were searched for articles concerning drugs and food anti-counterfeiting technologies, and the published literature from (2010 to 2021) was retrieved. The researchers thoroughly examined the selected publications to extract useful information, such as study design, use of those technologies in combating drugs and food counterfeiting, way of use, the effectiveness of those technologies against counterfeiting, evaluated outcomes, country of study, author(s) name, as well as publication year. A total of 29 publications were chosen and evaluated, with 22 (75.86%) of them reporting drug anti-counterfeiting technologies, 4 (13.79%) concerned with food anti-counterfeiting technologies, whereas 3 (10.34%) studies were based on both drugs and food counterfeiting technologies.Mostly, blockchain technologies 6 (20.68%) were used against counterfeiting, with most in China 8 (27.58%), and the highest number of reported studies was in 2021 (n=6; 20.68%), followed by 2016 and 2012 (n=5; 17.24%). Serialisation, SMS verification, RFID, and GSM technologies were used for drugs and food counterfeiting in single studies. It has been concluded that technological interventions are highly effective in combating drugs and food counterfeiting. However, technological interventions against food counterfeiting were considerably less than drug counterfeiting. Therefore, studies should be conducted on highly effective technologies, including blockchain, QR codes, Mobile authentication services, Internet of things, laser, web-based and three-dimensional technologies against food counterfeiting. Public awareness and knowledge about anti-counterfeiting technologies should be spread to help combat anti-counterfeiting through technologies.

Keywords: Technology; anti-Counterfeiting; counterfeiting; food; drug

Introduction

Drugs and food counterfeiting has been an economic and social long-standing concern, as it directly affects human beings owing to the essential significance of food and drugs for survival. The World Health Organization (WHO) has detected a rapid increase in food and medicine falsification, particularly in underdeveloped countries [1,2]. Causing an alarming rate of illness leading to deaths at all levels of human development. Furthermore, food counterfeiting is virtually ignored in the battle against counterfeiting, posing a more significant threat to society [3,4]. The phrases counterfeit, fake, and falsification are frequently used interchangeably. A counterfeit is a fraudulent medication or food, according to the Food and Drug Administration (FDA), which might be compromised, it could be missing or containing an incorrect active component, or they have a correct active component, but the dosage is incorrect [5,6].

Faking comprises either substitution, such as placing unsatisfactory products in genuine or recycled wrapping; including duplication of packaging, products, or instructions and tampering in which items and labels have been tampered with and the genuine item is replaced with a spiked or stolen product as well as return and warranty fraud [7]. Counterfeiting has always had a higher impact than the value of the counterfeited product. Counterfeiting tarnishes customer loyalty, brand reputation, and satisfaction by

affecting users' perceptions of the effectiveness, dependability, and reliability of brand products [8,9]. Organizations attempt to prevent counterfeits and address the motives for making a replica an appealing alternative for certain customers' actions to limit counterfeits that can originate from the supply and demand sides [10]. Counterfeit drugs range from recreational to lifesaving [11]. They can lead to adverse health implications and treatment failures, the development of medication resilience, and a loss of trust in healthcare institutions. All these factors add to the burden of illness, leading to increased morbidity and death [12].

The threat of counterfeiting drugs to patient safety and public health has afflicted the global community for a long time [13]. Various estimates suggest that millions of people might be put at risk because the global faking of medicine has grown into a billion-dollar industry, putting patients in developed and underdeveloped countries at risk [14]. Fake drugs can cause adverse health problems, including allergic reactions or fatalities. Drug manufacturers encounter brand problems and financial difficulties due to copyright and trademark violations, while governments in such areas yield substantial losses. Counterfeits account for more than 10% of the worldwide pharmaceutical business, with estimates indicating that 25% of counterfeited drugs are consumed in underdeveloped nations. Every year, up to 10,000 Africans are killed due to the consumption of counterfeit medicines, and governments throughout the globe lose 2 to 5% of their revenue [15]. Anti-malarial counterfeiting has been determined to be responsible for up to 267,000 additional fatalities per year, solely in Sub-Saharan Africa [16]. Thus, effective anti-counterfeit techniques must be developed to preserve the safety of patients across the drug supply chain [17,18].

Technological innovations present a fundamental change to enhance public health through the formation and implementation of clinically essential medications and therapies as well as an instrument to regulate food supply, as these technological interventions continuously create huge datasets for regulation purposes at a rapid pace [19]. However, using large data sets necessitates the creation of policies and methodologies for properly curating, analysing, and interpreting the data. This broad consensus will boost scientific evidence-based decision-making, and these advanced approaches will result in instruments to aid regulatory decision-making, medicine production, therapeutic uses, and better food supply management. Anti-counterfeiting technology safeguards brand identities, public safety, and supplier reputations. These technologies should be simple to use yet challenging to emulate in general.

They have four primary characteristics:

a) They are difficult to copy or fabricate.

b) They are immediately recognisable visibly without the use of any equipment.

c) They are challenging to re-label or reuse.

d) They are visible when altered. Various novel anti-counterfeiting technologies are now available for authenticating items or labelling while tracing and tracking products along supply chains which aims to identify and prevent counterfeiting [20].

Emerging technologies for assessing food and medication safety are promising for regulatory sciences. Numerous technological innovations have been presented to develop faster, less costly, but more predictive evaluation methods. Therefore, the current review was designed to systematically review the anti-counterfeit technological interventions combating drug and food counterfeiting. Previously [21,22]. systematically reviewed only drug counterfeiting through system-level interventions to assess their effectiveness. However, the current systematic review concerns technology use against food and drug counterfeiting. We conducted a current systematic review to better comprehend how technological interventions act as a unifying framework for many stakeholders concerned with solving a decades-long public health concern that necessitates new solutions to ensure product safety around the globe.

Methods

Following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria, the current systematic review was undertaken [23]. This systematic review was conducted without following any process. Table 1 shows the PRISMA checklist.

Searching Criteria

Different databases, including Scholar's portal journals, PubMed, Pub Fact, Google Scholar, ScienceDirect, Mendeley, Prime, and Scopus, were searched for relevant articles concerning "anti-counterfeiting technologies preventing drugs and food counterfeiting" from 2010 to 2022. For the current systematic review, published research articles in English were gathered. Keywords included anti-counterfeiting, technological interventions, combating counterfeiting of drugs, preventing counterfeit of foods, drugs and food counterfeiting, technologies against counterfeiting, drugs, and food anti-counterfeiting technologies as well as these keywords while using Boolean operator's "drugs" AND "anti-counterfeiting technology" OR "counterfeiting", "Counterfeiting" AND "Drugs", "Counterfeiting" AND "Foods", "anti-counterfeiting" OR "counterfeiting" AND "technology". Referenced published papers were carefully examined, and related titles were looked for and retrieved for pertinent data. In addition, other relevant literature was sought and included to explain and validate our present systematic review's conclusions.

Inclusion/Exclusion Criteria

The criteria for inclusion were:

a) technological use against drugs and food counterfeiting.

b) publications including food and drug information anti-counterfeiting technologies having all the data.

c) research articles having all the data in English whereas those articles dealing with:

a. survey types of anti-counterfeiting strategies to prevent the counterfeiting of drugs and foods.

b. technological studies against other products counterfeiting.

c. articles concerning other interviewing strategies combating food and drugs counterfeiting were not included in the current systematic review since they were out of scope.

Data Extraction

Mendeley reference manager was used to compile the data. Firstly, the relevant articles were downloaded from different websites and then uploaded to the Mendeley reference manager for better reading, extracting of data as well as referencing. The researchers thoroughly evaluated the selected papers to extract crucial information, such as study design, different technologies and their names, use of those technologies in combating drugs and food counterfeiting, way of use, the effectiveness of those technologies against counterfeiting, evaluated outcomes, country of study, author(s) name, as well as publication year. To organize the gathered data, graphs and tables were formed.

Quantitative Analysis

The Jaccard similarity index (JI) was computed to measure the similarities between the two groups of articles included in this review. One set was the "technology use against counterfeiting of drugs", and the other one was the "technological intervention against food counterfeiting" For JI similarity, the following formula was employed [24].

$$JI = c \times 100 / (a + b - c)$$

Where "a" represents the total number of anti-counterfeiting technologies against drug counterfeiting, "b" is the total number of food anti-counterfeiting technologies, and "c" is the number of technologies used against counterfeiting in both food and drug studies.

This section reviews, critiques, and synthesises primary literature on the anti-counterfeiting technological intervention preventing food and drug counterfeiting. The review highlights the gaps in the existing literature that underscore the need for this study. The review also takes in the variables used in this study. Although the current review focuses on technologies used against the counterfeiting of drugs and food, it will also highlight the similarities and differences between food and drugs anti-counterfeiting technologies.

Results

The initial search results yielded (n=148) research articles matching our intended study of the current systematic literature review. After removing 38 duplicates, we were left with 110 articles in an initial screening. Subsequently, the assessment of titles resulted in the removal of 28 articles concerning other data. After the assessment of titles, abstracts of the 82 left-out articles were thoroughly reviewed for the availability of all parameters, leading to the removal of 53 studies. Finally, 29 studies remained for detailed review concerning anti-counterfeiting technologies to prevent and combat the counterfeiting of drugs and foods. Those papers that were irrelevant or duplicated were deleted. Figure 1 illustrates the articles selection process.

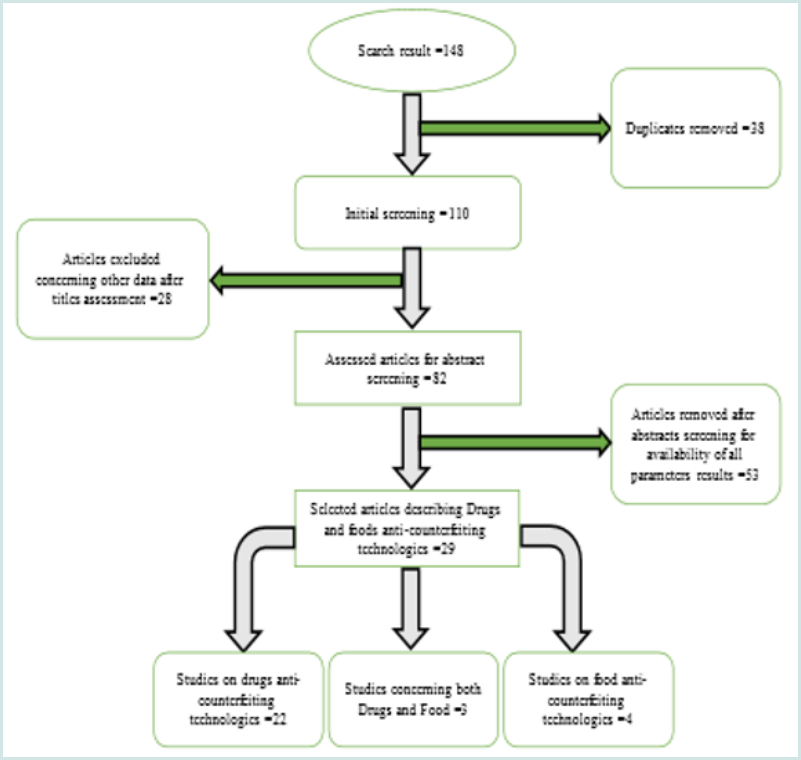

Figure 1: Articles Selection Process.

The chosen papers' quality was evaluated, and the articles were summarized by the author(s) name with year as a citation, country name, used technology, study design, the purpose of the study and finally, the findings of the study (Tables 1-3). Of 29 articles, 22 (75.86%) studies based on technologies reporting drug anti-counterfeiting, whereas 4(13.79%) reported food anti-counterfeiting, with 3 studies reporting both drugs and food anti-counterfeiting technologies (*n*=3; 10.34%). Studies reporting technologies based on drug anti-counterfeiting were more than those reported on the technologies on food anti-counterfeiting. More studies were carried out in China (n = 8; 27.58%), followed by the US, Nigeria, and India (n = 3; 10.34% each), followed by Hungary, Australia, and the United Kingdom reported (*n*=2; 6.89% each), and Saudi Arabia, Italy, Albania, Hong Kong, and Denmark reported (*n*=1; 3.44%) each as illustrated in Figures 2 & 3 respectively. The majority of the research studies were published in 2021 (*n* =6; 20.68%), 2016 and 2012 (*n* = 5; 17.24%), followed by 2018 and 2019 (*n* = 3; 10.34% each), then 2014, 2017 and 2020 (*n*=2; 6.89% each) and a single study were reported on drugs and food anti-counterfeiting technology in the year 2015 (*n*=1; 3.44%) (Figure 4).

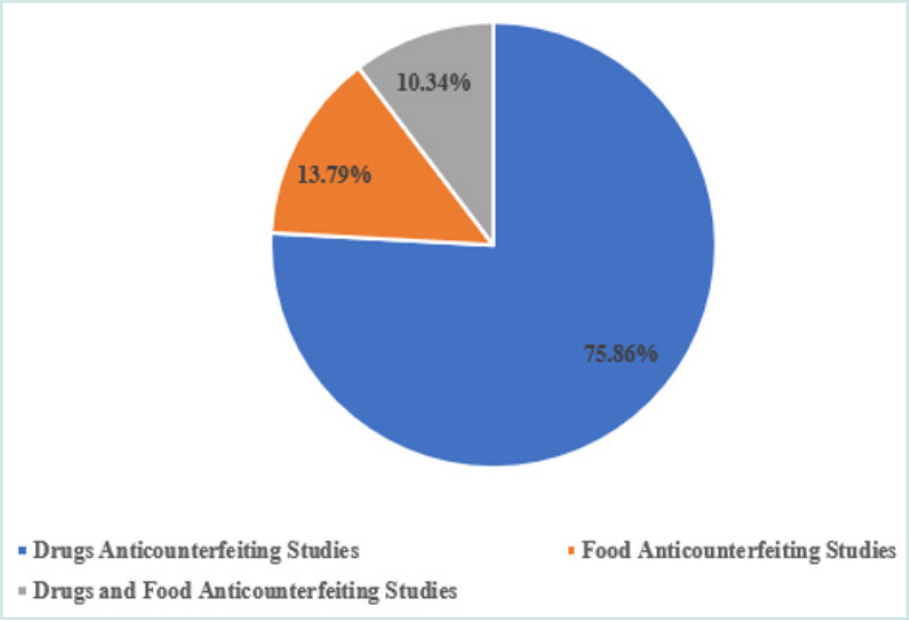

Figure 2: Anti-counterfeit Technological Studies.

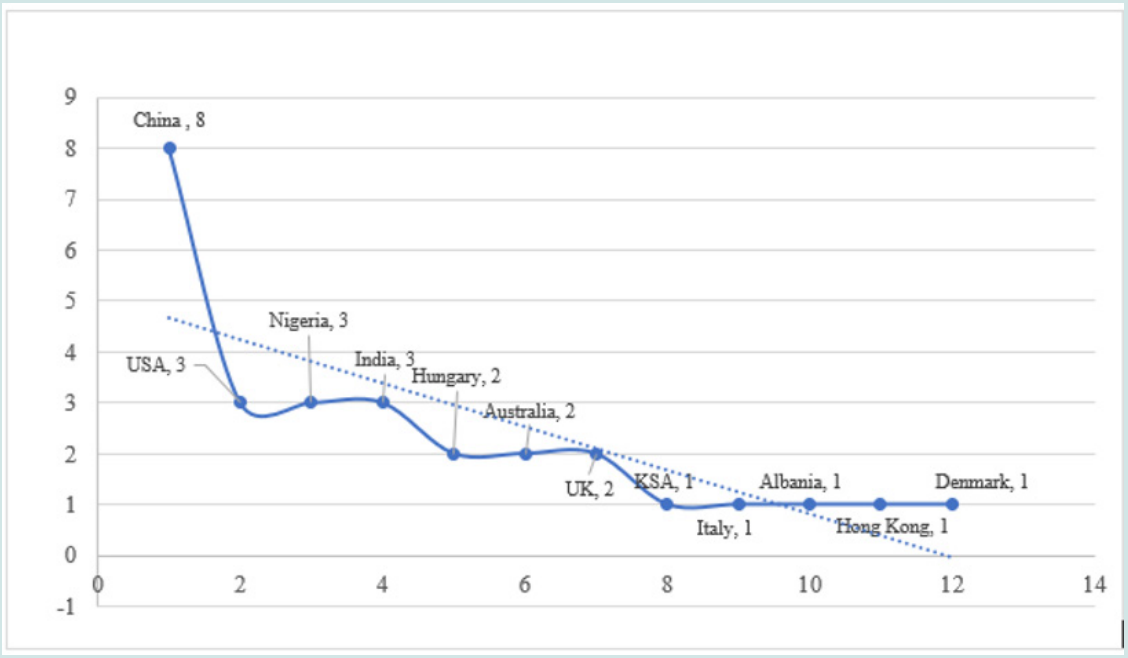

Figure 3: Country wise Anti-counterfeiting Studies.

Figure 4: Year Wise Food and Drug Anti-counterfeiting Studies.

Table 1: Showing Studies on Drugs Anti-counterfeiting Technologies.

Country	Study design	Technology	Purpose	Conclusion
Nigeria	Descriptive design (Sequential mix metho)	Mobile Authentication Service	The author's purpose in undertaking this study was to report the public awareness level of MAS use, public utilization assessment, public perception about the efficacy of the technology, factors affecting the use of technology as well as features affecting public awareness of the use of MAS [35].	The researcher concluded that MAS was very effective in the eradication of fake drugs in Nigeria; however, they also highlighted the limitations that most people have very less knowledge about MAS technology and public awareness is needed, especially in the rural areas, which will give better results
India	Innovative approach	Mobile Authentication Service	By suggesting a durable electronic health network based on blockchain, the authors seek to offer a solution to India's counterfeit pharmaceutical problem [26].	The authors found that blockchain technology allows patients to verify the validity of the drug they are taking while also ensuring that tax evaders do not take advantage of benefits intended solely for recipients.
China	Exploratory research	Blockchain	Decentralization key areas, essential system needs, and practical procedures for establishing decentralised anti-counterfeiting and traceable systems using blockchain technology are described [27].	In this exploratory research study, the researcher discovered the potential benefits of decentralizing existing supply chain anti-counterfeiting solutions that have been maintained solely by by-product producers, including improved data integrity with decentralized brand record management and state transitions on the product, records only approved if one 's corresponding payment is validated. Availability of components and data of product information supported by decentralised components and security concerns on data of product records processed with multi-layered validations is in place.
Hungary	Innovative approach	Laser Technology	The study aimed to establish a laser-based technique for putting a specific tracking barcode on the tablet's surface, which might also be used to designate individually tailored pharmaceuticals [36].	The results show that the KrF excimer lasers, as well as the Ti: sapphire femtosecond laser, are effective and dependable for labelling, appearing to be attractive prospects for pharmaceutical companies seeking to beef up their anti-counterfeiting protections.
Nigeria	Exploratory and descriptive design	Information technology services (SMS)	To obtain a better understanding of the public's perspective on the importance of technology in combating fraudulent pharmaceuticals and to enhance the current countermeasures used in Nigeria's fight against counterfeit and defective medicines [37].	The majority of those respondents answered that they were unaware of the use of information technology in combating bogus pharmaceuticals. Compared to their understanding of technological gadgets, their extent of awareness of Information Technology on bogus drug control is poor. This study revealed that in order to solve the issue of fraudulent pharmaceuticals in Nigeria, medicine users require a specialised information system

China	Innovative approach	Internet of Things (IoT)	An IoT-based traceable medication anti-counterfeiting management system was proposed by the researcher, having a complete strategy including medical research and development as well as production, sales and certification [38].	The proposed framework satisfies the information security criteria of data integrity, irrevocable information, replay resistance and non-repudiation. Additionally, attaining the core aim of anti-counterfeiting of medications, the integration of the Internet of Things and blockchain technology has also achieved the objectives of automated supply chain management
Saudi Arabia	Innovative approach	IoT	The authors proposed a new IoT-based authentication methodology for anti-counterfeiting medicine systems, which will aid in determining the legitimacy of a drug's "unit dose." [39].	The authors developed a unique authentication technique that is resistant to the majority of known weaknesses while also providing extra security mechanisms at nearly the same processing cost. It aids in verifying drug authenticity, and the technique may be utilised to combat drug counterfeiting for enhanced protection.
USA	Innovative approach	Fluorescent Inks technology for direct printing on pharmaceuticals (semi-covert fluorescent security label)	To imitate anti-counterfeiting technologies and provide an extra degree of protection [40].	This finding suggests that non-toxic inks could be used as a semi-covert verification approach for some over-the-counter pharmaceutical drugs. Using these Inks to authenticate pharmaceuticals could eventually provide a simple way for physicians and consumers to spot counterfeits.
India	Innovative approach	IoT	In the Internet of Things context, a novel authentication strategy for medication anti-counterfeiting system that is used to assess the validity of pharmaceutical items was proposed [41].	The suggested technique has been demonstrated to be secure against several known attacks. Additionally, the suggested method is secure after strict security assessment utilising the sophisticated and widely utilised AVISPA tool. Moreover, they constructed the suggested method using the widely used NS2 simulator, and the simulation results show that the strategy is feasible. Overall, the suggested system is acceptable for the anti-counterfeiting of medicinal dosages due to a better trade-off between security, extra functionality features, and efficiency
China	Innovative approach	Three-Dimensional (3D) Quick Response (QR) technology	To create a smartphone identification model based on an up-converted florescent three-dimensional (3D) quick response (QR) code for drug tracking and counterfeiting [18].	The authors found that the created 3D QR code technology has advantages due to its low cost, ease of handling, maximum speed, and high information capacity, which hold tremendous promise for the anti-counterfeiting of medicinal applications.
Denmark	Innovative approach	Nanotag luminescent fingerprint	The authors describe a technique for fabricating, transferring, as well as validating anti-counterfeiting nanofiber-based unique security markings ('nanotags') using image processing [42].	Using bottom-up generated arrays of ordered organic nanofibers, the researchers demonstrated a way of creating unique nanotags for product anti-counterfeiting. The nanotags that arise may be easily applied to a variety of objects using transparent adhesive foils. Upscaling the process to mass production is not difficult due to the ease of fibre array creation
China	Exploratory	Blockchain	The new system's goal is to embrace blockchain technology's characteristics, bring traceability and safety to the pharmaceuticals supply chain, and provide insight to producers and medication regulators [28].	The authors proposed further use of blockchain technology in healthcare. They discussed the problems with existing drug supply chain management and how blockchain might be utilised to improve medicine supply chain transparency and visibility while combating counterfeiting. The identification mechanism of blockchain technology is described, as well as how it may be used to communicate medical information while maintaining the patient's personal information private. They also go through the various approaches, blockchain types, and third-party technologies that may be utilised to create a blockchain-based pharmaceutical supply chain. Finally, they also demonstrated how the proposed system works with an example showing how the system may be utilised by a variety of stakeholders
Nigeria	Investigative	Mobile Authentication Service	The existence of MAS codes on pharmaceuticals required by NAFDAC to have the code was evaluated, as well as an initial evaluation of MAS effectiveness [43].	The results of this investigation indicated that several anti-malarial and antibacterial medications on the Nigerian market still lack MAS technology, and the efficiency of the Mobile Authentication Service is directly proportional to the competency of the service providers permitted to operate it

Republic of Korea	Innovative approach	QR-coded micro taggant	A QR-coded micro taggant with higher efficiency and error-correction capabilities is presented for the anti-counterfeiting of pharmaceuticals [17].	By permitting the encoding of a vast quantity of pharmacological information, the suggested system enables authentication and the potential of track-and-trace. Furthermore, due to its error-correcting capabilities, substantial damages during medication manufacturing may be tolerated, and the code is read using a simple smartphone QR Code reader application available worldwide. These qualities add to the micro taggant's practicality and thus are implemented utilising a standard QR Code technology platform.
China	Exploratory	Overt anti-counterfeiting technologies	This experiment aimed to show that using an OACT can impact patients' inferences about the authenticity of dubious drugs [44].	The authors concluded that the model used in this study might be applied to additional items in the health (e.g., alcohol, cosmetics, and food) and safety (e.g., bike helmets and fire extinguishers) categories, as counterfeit products in these categories can be harmful to consumers. The findings of this work have a broader application when it comes to anti-counterfeiting research employing OACTs for such items. In conclusion, the author proposes that companies and policymakers examine the influence of anti-counterfeiting methods on consumer inferences when considering anti-counterfeiting strategies in order to make better judgments
China	Innovative approach	Drug-laden biodegradable label technology using QR code	For the anti-counterfeiting of pharmaceuticals, the authors proposed an encoded 3D drug-laden biodegradable label without fluorescent tagging [45].	By laser engraving and micro moulding a QR code suited for anti-counterfeiting of medications, they produced a drug-laden encoded 3D biodegradable polymer micro-label that is ideal for many states of pharmaceuticals, including powder, troche, and granule
United Kingdom	Two-stage quantitative secondary care study	Technical Detection Rate (TDR) and Operational Authentication Rate (OAR) of technologies	Using medication authentication technology, researchers will determine the rate of serialized medicine authentication technology [5].	The medicines authentication technique meets the FMD-mandated response time of 300 milliseconds and has a TDR of 100 per cent. The OAR needs to be improved, which might be aided by creative and interactive teaching and training or by introducing incentives like "paying by authentication."
Hungary	Innovative approach	Laser coding	Because this treatment reduces the chemical degradation of the coating film throughout the procedure, the inquiry recommends using an excimer UV laser to label the tablet surface [46].	According to the researcher's findings, the excimer UV laser is the best labelling technology in anti-counterfeiting tagging on solid-coated tablets since it produced the lowest degree of chemical degradation of the polymer film.
India	Innovative approach	System dynamics	The research proposes a dynamic theory that builds on an integrated approach, challenging how counterfeit medication supplies have been handled [47].	The simulation findings demonstrate that accelerating technology use and public outreach, in combination with strict licencing and assessment controls, can dramatically reduce the instances of counterfeit medication supply
Australia	Innovative approach	Web-Based technology	The authors proposed a comprehensive model that seeks to capture an advancing technology, such as an RFID-based approach [48].	Researchers created, developed, and demonstrated the use and deployment of such a system. Using the RACB system, retail and other sectors may monitor a fake product accurately and quickly at the time of purchase without human intervention, allowing these businesses to reduce costs in improving security while also playing an important management role. While RFID-based systems provide promised benefits such as retail or other business process automation, certain substantial hurdles (such as security and privacy problems, as well as handling RFID data) must be overcome before these advantages can be realised.
United Kingdom	Innovative approach	Three Dimensional (3D)	For the first time, this work reports the interface between 2D inkjet printing and 3D technologies to create a drug-loaded 3D printed tablet with a novel track-and-trace mechanism in a one-step approach [49].	The study was the first to use a combination of 3D and 2D printing techniques to develop a drug-loaded printlet with dual track-and-trace and anti-counterfeit mechanisms. A unique anti-counterfeit technique was developed, including the deposition of a one-of-a-kind mixture of materials that were effectively identified through Spectroscopic techniques. This double-printing approach may offer advantages when tracing customized medications along the supply chain, from prescriptions to distribution and compliance.

Austra-lia	Innovative approach	Web	Using the Elliptic Curve Cryptographic (ECC) approach, this study presents an asymmetric cryptosystem to protect RFID transmission in the retail supply chain [50].	To combat counterfeit branding, the researchers created a Web-based Anti-counterfeit RFID System (WARS). The authors demonstrated the use and practical implications of the technology above. Efforts are being undertaken to create a full system (i.e., WARS) for use in retail sectors to combat counterfeiting. It also offers a distinct security layer in the WARS design to handle RFID security challenges, as well as a dependable suitable security measure such as authenticity, secrecy, and intractability via wireless communication utilising public-key cryptosystems (ECC). The key strengths of ECC, above other public-key systems such as RSA, DSA, and others, are higher security and more efficient performance.

Table 2: Showing Food anti-counterfeiting technology studies.

Country	Study design	Technology	Purpose	Conclusion
China	N/A	FTA-PCR (Flinders Technology Associates-Polymerase Chain Reaction) with LIMS (Laboratory Information Management System)	To ensure the safety of food using a mix of traditional testing and biotechnology [51].	The researcher examined an FTA-PCR technology with a LIMS system that combines lab management requirements. It is more practical and unique with a quicker experimenting time, resulting in more areas of food safety being assured
Italy	Multi-ple-case study	Blockchain	This study aims to contribute to the debate on blockchain (BC) implementation to avoid counterfeiting [25].	The authors indicate that the required level of upstream and downstream counterfeit control leads to BC operating system selections since their potential to limit fraudulent threats varies. The greater the needed degree of security, the more firms select BC alternatives that may decrease fraud chances to a larger extent
Albania	Inno-vative approach	Encrypted QR codes in mobile systems	The goal is to deliver a mix of Quick Response (QR) coding and anti-counterfeiting technology via mobile platforms employing encryption methods [52].	The authors demonstrated the first stage of establishing this architecture for the "Made in Albania" trademark in terms of security), traceability, and transparency for consumers. It investigated the primary data carriers, including RFID chips, barcodes and RFID chips, and the systems that rely on them.
Hong Kong	Inno-vative approach	Blockchain–IoT-based food traceability system (BIFTS)	To meet the demands for food traceability, lightweight and vaporized qualities are applied in the blockchain, while an integrated consensus mechanism that takes into account shipment transit time, stakeholder evaluation, and shipment volume is being established [29].	The researcher's findings are derived from food tracking in an e-commerce business setting, specifically for managing fresh food. Aside from the previous, implementing the combination of blockchain and IoT is advantageous to small and medium-scale enterprises (SMEs) rather than solely enterprise-level applications in business transactions, commerce, and manufacturing.

Table 3: Showing Studies concerning both Drugs and Food anti-counterfeiting Technologies.

Country	Study design	Technology	Purpose	Conclusion
Nigeria	Compara-tive study	Serialisation and SMS verification	The goal of this research is to compare anti-counterfeit technological solutions to provide a long-term and effective preventative strategy against counterfeiting in emerging countries [3].	It was found that the low amount of medicine counterfeiting observed in industrialised nations may be linked to the level of technological solutions used to ensure optimal tracking and originality of all pharmaceuticals. It was suggested that underdeveloped countries use comprehensive serialisation technologies with data career (particularly RFID) systems on all pharmaceuticals and foods.
Nigeria	An ex-ploratory study of innovation	GSM (Global System for mobile communication)	The suggested GSM system research would assist users in accessing information about an item efficiently without losing time and energy, as long as there is a GSM network servicing that location [33].	The SMS-based NAFDAC Registration Exercise is a novel idea that demonstrates the capabilities of SMS in GSM applications. This effort is a novel breakthrough that will aid in reducing the threat of counterfeit pharmaceuticals in our society. This work is easily adaptable to meet the requirements of any potential user and is closely comparable to applications that involve wireless access to a distant database.
USA	Explor-atory	RFID	To develop novel sensors (nano sensors, biosensors, and radio frequency identification (RFID) sensors) that might be used in labelling, specifically medicinal and food packaging [34].	The authors stated that sensor technologies are potential anti-counterfeiting techniques that can aid in the prevention of food and pharmaceutical product fraud

Numerous Technologies used against Food and Drug Counterfeiting

Primarily, Blockchain technology was used in the reported studies for anti-counterfeiting of foods and drugs comprising (n=6; 20.68%), then laser and mobile authentication SMS-based technology (n=3; 10.34%), followed by Quick Response codes (QR), Internet of Things (IoT), web-based and Three Dimensional (3D) anti-counterfeiting technologies (n=2; 6.89%) each. Last were those anti-counterfeiting technologies reported in a single study (n=1; 3.44%) each: nanotechnology, system dynamics, Fluorescent Inks technology, overt anti-counterfeiting technologies, Global System for Mobile communication (GSM), Radio Frequency Identification (RFID), Technical Detection Rate (TDR) and Operational Authentication Rate (OAR), and Flinders Technology Associates-Polymerase Chain Reaction (FTA-PCR) with Laboratory Information Management System (LIMS).

Similar Technologies used for both Drugs and Food Anti-counterfeiting

Several studies that assessed both drugs and food anti-counterfeiting technologies are shown in Tables 1 & 2 respectively. Serialisation and SMS verification, RFID, and GSM technologies were used for drugs and food counterfeiting in single studies. Two studies were carried out in Nigeria, while another was conducted in the US based on exploratory and comparative study designs. The Purpose of the Serialization and SMS verification study was to comparatively analyse the anti-counterfeiting technologies to ensure a long-term and efficient combative indicator against counterfeit products in underdeveloped countries. In contrast, the purpose of the global system for mobile authentication was to help users effectively obtain data on a product without squandering time and energy as long as a GSM network covered that area. Blockchain, IoT, and QR codes are the common technologies used against drugs and food counterfeiting.

Jaccard Similarity

Drug and food anti-counterfeiting technologies were assessed for common studies through the Jaccard similarity index formula resulting in 7.14% similarities.

Discussion

The current systematic review was conducted on technological interventions combating drugs and food counterfeiting. Overall, we identified 29 studies based on food and drug technologies against counterfeiting. Several criteria were identified as crucial to the effective design and execution of technology solutions to fight or prevent medication piracy. Previously, regulatory measures, including medication registration and WHO prequalification, as well as onsite quality checks, which were major components of comprehensive interventions, were proposed as effective means of lowering the incidence of fraudulent and inadequate pharmaceuticals. The current systematic review mainly reported on blockchain technologies as an emerging intervention to prevent the counterfeiting of drugs and foods (n=6; 20.68%). Numerous researchers are debating various BC feeding and reading choices to supplement BC technology, as well as the implications for counterfeiting. The primary priority is guaranteeing the accuracy of the input data [25].

Some researchers concluded that blockchain technology provides authenticity and ensures the safety of drugs to the patients and also ascertains that the tax evaders do not misuse the privileges meant only for the beneficiaries [26,27] discovered the potential benefits of decentralising existing supply chain anti-counterfeiting solutions that have been maintained solely by by-product producers, including improved data integrity with decentralised brand record management and state transitions on the product, records only approved if one's corresponding payment is validated. The authors proposed further use of blockchain technology in healthcare. They discussed the problems with existing drug supply chain management and how blockchain might be utilised to improve medicine supply chain transparency and visibility while combating counterfeiting. The identification mechanism of blockchain technology is described, as well as how it may be used to communicate medical information while maintaining the patient's personal information private.

They also go through the various approaches, blockchain types, and third-party technologies that may be utilised to create a blockchain-based pharmaceutical supply chain. Finally, they also demonstrated how the proposed system works with an example showing how various stakeholders may utilize a system [28]. The authors indicated that the required level of upstream and downstream counterfeit control leads to BC operating system selections because their potential to limit fraudulent threats varies. The greater the needed degree of security, the more firms select BC alternatives that may decrease fraud chances to a larger extent. The researcher's findings are derived from the field of food tracking in an e-commerce business setting, specifically for managing fresh food. Aside from the preceding, implementing the combination of blockchain and IoT is advantageous to small and medium-scale enterprises (SMEs) rather than solely enterprise-level applications in business transactions, commerce, and manufacturing [29]. These investigations show that BC technology can ensure product originality compared to traditional procedures, including both general and the food sector, in particular, are in agreement with [30-32].

Comparative studies on both food and drugs technologies

Previously, systematic reviews did not address both food and drug technologies. However, it is commonly known that anti-counterfeiting technologies against food and drugs are highly effective and prevent counterfeiting [33,34]. The previous systematic reviews focused on system-level intervention, while the current research focused on technological interventions against both drugs and food counterfeiting. We identified three studies based on drugs and food anti-counterfeiting technologies gave future recommen-

dations and assessed those technologies' effectiveness. Proposed that emerging countries should deploy full serialisation technology with information career (particularly RFID) mechanisms on all food and drug outlets. They concluded that less drug counterfeiting is reported in developed economies due to the high level of technology interventions implemented to ensure optimum authenticity and traceability of products. RFID technological studies found that the sensor technologies were promising anti-counterfeiting tools helping in food and drug counterfeiting products are in disagreement with the previous systematic review showing concern on the effectiveness of RFID track and trace system in combating counterfeiting. However, supported the conclusion that RFID and mobile authentication technologies such as GSM are highly effective in tracking and tracing, helping to combat the menace of product counterfeiting in society, as concluded.

Strengths and limitations

According to the best of our knowledge, the strength of the current systematic review is that is the first anti-counterfeiting emerging technologies review concerning both drugs and food counterfeiting. This systematic review includes articles and conference papers on food and drugs anti-counterfeiting technologies retrieved from multiple databases, ensuring our search's inclusiveness. Limitations include single studies on different anti-counterfeiting food and drug technologies that limit our ability to draw any conclusions regarding that technology's effectiveness. Another limitation was that only those studies concerning food and drugs anti-counterfeiting technologies published in English from 2010 to 2021 were included.

Conclusion

Technological interventions are highly effective in combating drugs and food counterfeiting with blockchain, mobile authentication services, and QR codes are the most effective technologies. However, the use of technological interventions against food counterfeiting was considerably less compared to drug counterfeiting. Therefore, studies should be conducted on highly effective technologies, including blockchain, QR codes, Mobile authentication services, Internet of things, laser, web based as well as three-dimensional technologies against food counterfeiting. Public awareness and knowledge about anti-counterfeiting technologies should be spread to help combat counterfeiting.

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