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Supply chain management for online pharmacies: An exploration of operations, pricing, counterfeit medicine and technology uptake

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ABSTRACT

The global online pharmacy sector is set to double its size in the next couple of years; a forecast highlighting its crucial and still rapidly emerging impact in healthcare. Using a theme-based narrative literature review covering academic publications through years 2013 to 2022, this study describes the role of Supply Chain Management (SCM) for online pharmacies by identifying and contextualising four industry-defining themes. These are namely *dual-channel operations* (i.e., synergies between online and traditional pharmacies), *pricing strategies* (e.g., balancing profitability and affordability), *legitimacy challenges* (i.e., are any medicine counterfeit?), and *technology's transformative impact* (e.g., AI and blockchain operations are paradigm-changers). The study highlights the urgency of regulatory collaboration and rigorous oversight for secure and efficient online pharmacy supply chains and exposes the reader to the current challenges and opportunities underpinning the online pharmacies' SCM. This work enhances the academic understanding of an emerging sector and provides practical insights for online pharmacy businesses about tackling barriers that may disrupt or diminish supply chain efficiency. As the sector grows, these evidence-based insights can assist strategic decisions, policy formations, and technological progress, fostering improved global healthcare access.

1. Introduction and background

Online pharmacy refers to an internet-based vendor, whether lawful or unlawful, engaged in the sale, delivery, distribution, or dispensation services of medication directly to consumers [1]. This vendor may function independently online, as an extension of a physical pharmacy, or as a collaborative platform among multiple pharmacies [1]. The rise of online pharmacies is a significant disruption to pharmacy markets worldwide, enabling patients to purchase medications at lower costs than traditional retail pharmacies [2–4]. Valued at over $81.6 billion, the global online pharmacy sector is projected to reach $244 billion by 2027 [2]. Key markets driving this growth include major manufacturers in China and India, and packaging and distribution in Europe, South America and Asia [2,5].

The pharmaceutical e-commerce sector experienced significant growth during the pandemic, with CVS reporting a 1000 % surge in online prescription orders in the early stages [6]. For instance, in Norway, the immediate surge in home-delivery requests from pharmacies resulted in significant supply chain bottlenecks, exceeding service capacity limits and leading to sold-out situations with backorders accumulating days in advance due to these constraints echo the bullwhip effect [7]. This trend with demand variability due to pandemic shutdowns further amplified the upstream in the supply chain, prompting pharmaceutical vendors and manufacturers to prepare proactively to compete in this rapidly expanding market during the challenging times [6].

For businesses, online pharmacies offer distinct advantages over traditional brick-and-mortar pharmacies, including enhanced accessibility, convenience, cost-effectiveness, and streamlined operations [8]. These benefits reduce medicine expenditure for customers and optimise sale volumes for businesses, creating a mutually beneficial landscape. With 66 % of the global population having Internet access in 2022 [9], the potential for online pharmacy expansion is significant. Factors driving this growth include increased Internet access, improved doctor-patient interactions, online consultations, self-assessment trends, and enhanced online purchasing experiences [10].

Simultaneously for customers, key advantages include convenience, competitive pricing, and access to scarce medications [1,11]. In India, for instance, benefits such as purchase confidentiality, attractive discounts, affordability, home delivery, a wide selection of substitutes, and

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refill reminders significantly influence the adoption of online medicine purchases [4]. Despite limitations like transport time, these advantages contribute to the sector's rapid growth [12].

In the United States, adults increasingly resort to online pharmacies to alleviate the burden of high out-of-pocket expenses linked to prescription drugs. Unlike other countries, the significant cost burden in the US makes online pharmacies attractive to cost-conscious consumers [3]. This pricing discrepancy has led around 8 % of Americans, approximately 19 million adults, to purchase prescriptions online from overseas, yielding savings of over 50 % [13]. Despite being illegal, law enforcement is lax due to difficulties of monitoring small package deliveries, creating opportunities for counterfeit and substandard drugs to infiltrate the market [3].

While convenient, online pharmacies face challenges like concerns about authenticity, outdated medications, insufficient information, erroneous orders, and accessibility of specific brands prescribed by doctors [4]. In the US, restrictive laws, clinic closures, and economic barriers complicate access to formal healthcare, leading some individuals to explore online pharmacies for services like abortion pills without prescriptions, driven by convenience, perceived autonomy, and privacy [14].

Amidst the convenience, concerns have surfaced regarding the legitimacy of online drug purchases, visibility of patient authorisation for medicine access, and logistical and temperature control issues [15]. Addressing these matters requires thoughtful consideration and regulatory measures to ensure the secure provision of pharmaceuticals through online platforms [15].

Furthermore, studies in China conclude that online pharmacy customers prioritise logistics speed, followed by drug price and customer service and assign the least emphasis on drug effects [16]. This is alarming since China's ageing population and rising chronic diseases suggest online pharmacies' potential to provide consistent medication supply, can be game-changing [16]. On the other hand, online pharmacies have also made positive contributions to society by raising awareness about medicines, also strive to support patients adhering to their prescription regimens by offering refill reminder services for timely medication replenishment [12].

Amidst the expanding global online pharmacy sector, this thematically organised narrative review examines online pharmacy SCM within these lines. The study aims to review the start of the art in this critical domain by evaluating methodologies, recurring themes, and trends. It is specifically highlighting challenges such as legitimacy concerns, regulatory complexities, and logistical issues, in an effort to provide evidence-based insights aimed at enhancing supply chain efficiency. The review offers a pragmatic analysis, acknowledging sector intricacies and limitations, and provides practical insights to support strategic decision-making and progress in the online pharmacy industry.

Henceforward the paper presents in Section 2 the methodological framework adopted. Section 3 presents the literature corpus, Section 5 discusses our results and Section 5 contextualises and benchmarks the key findings against the literature. Finally, the last section concludes the paper by highlighting the contributions made, reflecting on the work's limitations and illustrating paths for further research.

2. Methodology

2.1. Overview of review process

This work represents the results of a thematically organised narrative review exploring the SCM of online pharmacies. To ensure a high standard of quality and consistency, the systematic literature review principles as per Van Wee & Banister [17] were adhered to in selecting articles and formulating search strategies [17]. Additionally, dual reviewer screening was conducted using the Scopus database; all records were independently screened by two reviewers and one critical examiner at each stage (title, abstract, and full-text), with discrepancies resolved through discussion to ensure thorough coverage of the relevant literature.

The literature search was conducted exclusively through the Scopus database, and research methodology employed in this study goes beyond the conventional approach by including real-world case studies (in line with Nikitas, Thomopoulos and Milakis, [18]) to analyse well-established and advanced SCM techniques utilised in e-commerce businesses. This review aims to provide recommendations to online pharmacy businesses and policymakers based on the insights derived from the literature.

2.2. Inclusion criteria and search strategy

The search scope was limited to peer-reviewed Scopus-indexed academic journal articles, published in English, between 2013–2022 were the material studied. For the Scopus search, filters were applied to titles, abstracts, and keywords to identify the most relevant papers for this review. Alternative terms such as "logistics" and "distribution" also substituted "supply". Additionally, "e-pharmac*" and "digital pharmac*" were used as synonyms to "online pharmacy*", so that pharmacy-related terminology is widely represented (see Table 1).

The review includes relevant publications from credible organisations beyond the defined search criteria. This approach helps reduce publication bias and enriches the research by integrating real-world implications with academic perspectives [18,19].

2.3. Study selection

The authors examined 124 abstracts of peer-reviewed articles from Scopus. After screening articles on the basis of titles, keywords and abstracts, 22 articles were retrieved of which, a total of 18 studies met the eligibility criteria and were included in the review (see Fig. 1). Although the first online pharmacy was established in 1999, the academic literature on this domain remains sparse, highlighting it as an under-researched area [20].

3. The literature corpus

The review found that online pharmacy SCM research is diverse, covering various research streams but rather fragmented. The 18 selected publications were published in 17 unique research journals (see Table A1). A similar fragmented pattern is observed among authors, with a total of 69 authors identified; only three authors contributed to more than one publication (see Table A2). The following section provides an overview of the research streams identified in the literature, the evolution of reviewed articles, and the methodologies employed in the respective studies.

3.1. Research streams

The publications under review refer to different research streams. Inspired from the principles of thematic analysis [21], which is a well-embraced, rigorous and scientifically sound method for identifying, organising, and offering insights into patterns of themes across several items of qualitative data [22] the authors systematically identified through coding and mapping four prevailing themes. These themes emerged naturally by reading and re-reading the data corpus and identifying critical patterns occurring again and again in the text; the themes were not influenced therefore, as often is the case, by a preconceived theoretical framework which creates some bias [23]. The authors followed best practice [24], to further eliminate subjectivity, so each of the two reviewers first identified a set of initial themes independently, that were scrutinized by the critical examiner and then all four authors as a group had a 'synthesis' round table discussion to reach a definitive consensus about the final themes going forward [24]. Through detailed analysis and mapping of selected studies, the authors

Table 1
Search strategy.

Search Strategy
SCOPUS TITLE-ABS-KEY (("supply" OR "logistics" OR "distribution") AND ("online pharmac*" OR "e-pharmac*" OR "digital pharmac*") AND "AI") AND PUBYEAR > 2012 AND PUBYEAR < 2023 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))

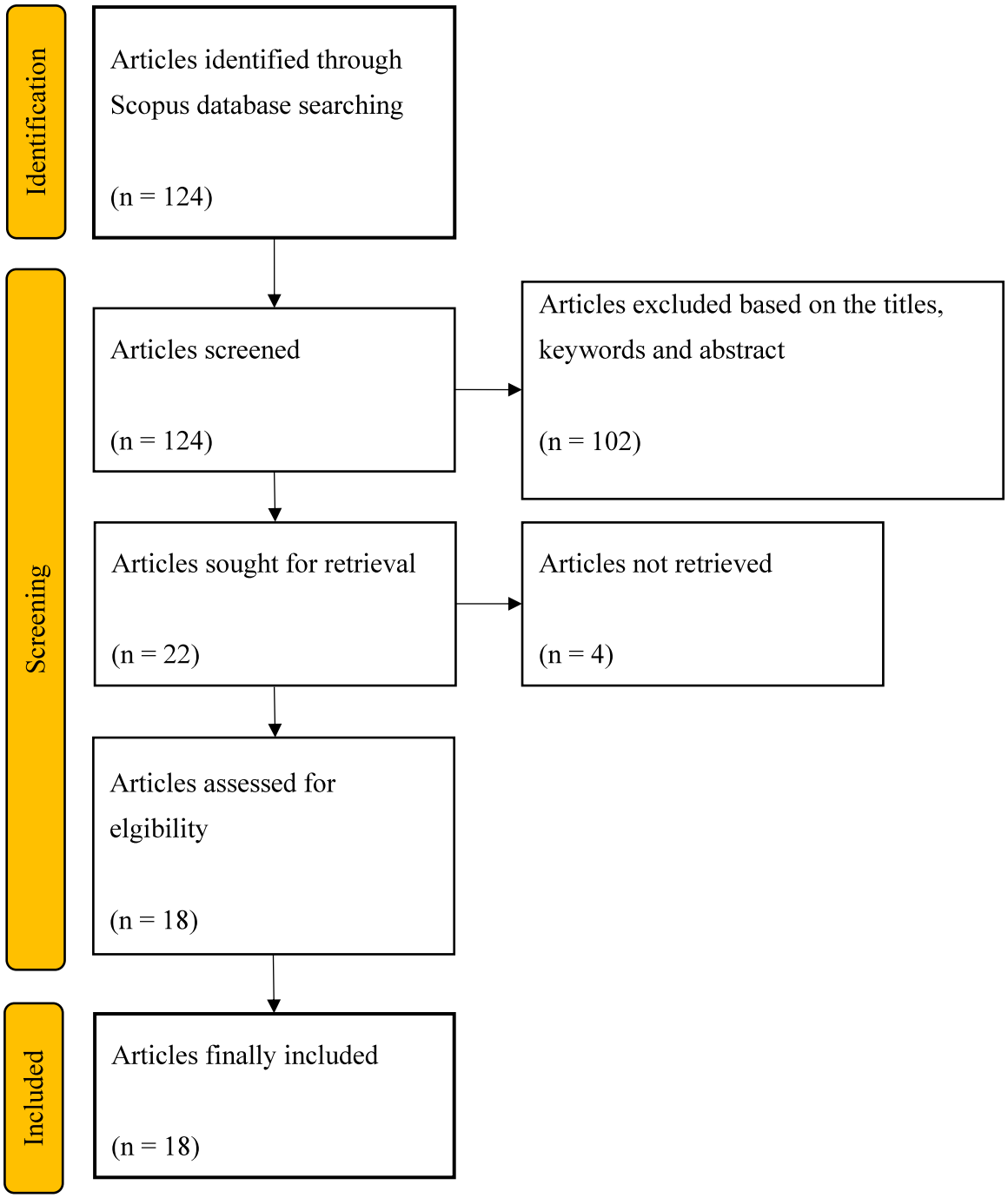

Fig. 1. PRISMA-style flow diagram of the publication retrieval process.

categorised the publications into the following themes: *Dual Channel Operations, Pricing, Legitimacy, and Technology* (see Table 2 & Table A3) [12,25].

Acknowledging the range of perspectives found in the articles regarding common themes, this analysis explores the research scope to reveal its limitations and the potential applicability of insights across a broader context. The interconnected nature of these themes introduces complexities in assigning a single theme to each article, sometimes leading certain articles to be affiliated to multiple themes. Notably, 10 papers refer to more than two themes in their exploration. Within this

Table 2
Number of articles within each theme.

Theme	# Articles
Dual Channel Operations	5
Pricing	6
Legitimacy	9
Technology	10

context, the review distils insights within distinct thematic strands, navigating their interconnections and limitations. This effort consolidates the insights within each theme and explores the interlinks and limitations of these insights, offering a comprehensive understanding of the role of SCM in online pharmacies.

More specifically, the four themes that emerged from this work were: *Dual Channel Operations*, which delves into the opportunities and challenges associated with pharmacy omnichannel operations involving both online and offline presence; *Pricing*, which explores the effects of competitive pricing and distribution optimisation in online pharmacies, focusing on drug affordability and its impact on overall business profitability; *Legitimacy*, which investigates the rise of illicit online pharmacies, its significance, impacts, and strategies for raising awareness and mitigation; and *Technology*, which highlights the potential for technology integration within online pharmacies, providing solutions to various challenges discussed across different themes.

3.2. Evolution

Over the time, spanning from 2013 to 2022, the publication rate exhibited fluctuations. From 2013 to 2017, the rate remained relatively low, with only 0–1 publication per year. However, between 2018 and 2020, publications increased to 2–3 per year. In 2021, there was only one publication, but there was a significant surge in 2022, with eight articles published (see Fig. 2). Notably, there has been a notable rise in technology and legitimacy-related publications. This increased interest can be attributed to the growing customer adoption of online pharmacies worldwide, particularly after experiencing medicine access challenges during the pandemic. Rising customer demand and increased research activity concerning SCM in online pharmacies highlights the importance of conducting thematic analysis. This approach aims to organise existing research and establish a platform for future research.

3.3. Study locations

Many of the 18 studies were centred in three market regions, specifically India, China, and the US (Table A4). Examining diverse themes, dual channel operations (5) studies were dominant in China (3 out of 5). Pricing papers (6) were affiliated to China (2 out of 6) and India (2 out of 6). Legitimacy inquiries (9) were notable in the US (3 out of 9), India (2 out of 9), and global studies (2 out of 9). Technology (10) garnered substantial attention in India, with 5 out of 10 studies (see Table 3). Strikingly, Glass [26] showed that 54 % of counterfeit drugs are from India and 21 % from China [26]. Given the gravity of these counterfeit drug risks, it is intriguing to note the limited research activity devoted to legitimacy themes within the purview of online pharmacy supply chain operations.

A gap analysis matrix in (see Table 3 and Fig. 3) highlights uneven geographic and thematic coverage in the literature on market access strategies. Jordan, Taiwan, and the United Kingdom have no studies captured across the four domains examined dual channel operations, pricing, legitimacy, and technology indicating limited published evidence in these settings based on the current sample. India shows the highest number of unique studies ($n = 6$), though the focus is predominantly on technology ($n = 5$), with fewer studies addressing operational or regulatory themes. China and the United States contribute across multiple domains, but gaps remain, such as the absence of studies on dual channel operations in the U.S. Global studies are present in each domain but are few in number ($n = 3$), limiting the extent to which they can inform cross-context comparisons. These patterns point to areas where further research could strengthen the evidence base, particularly

Table 3
Gap-analysis matrix displaying study location and theme of journal articles included in this review.

Country	*Unique studies*	Dual channel operations	Pricing	Legitimacy	Technology
China	*3*	3	2	1	1
Global	*3*	1	1	2	1
India	*6*	1	2	2	5
Jordan	*1*	-	-	-	1
Taiwan	*1*	-	-	-	1
United Kingdom	*1*	-	-	1	-
United States	*3*	-	1	3	1

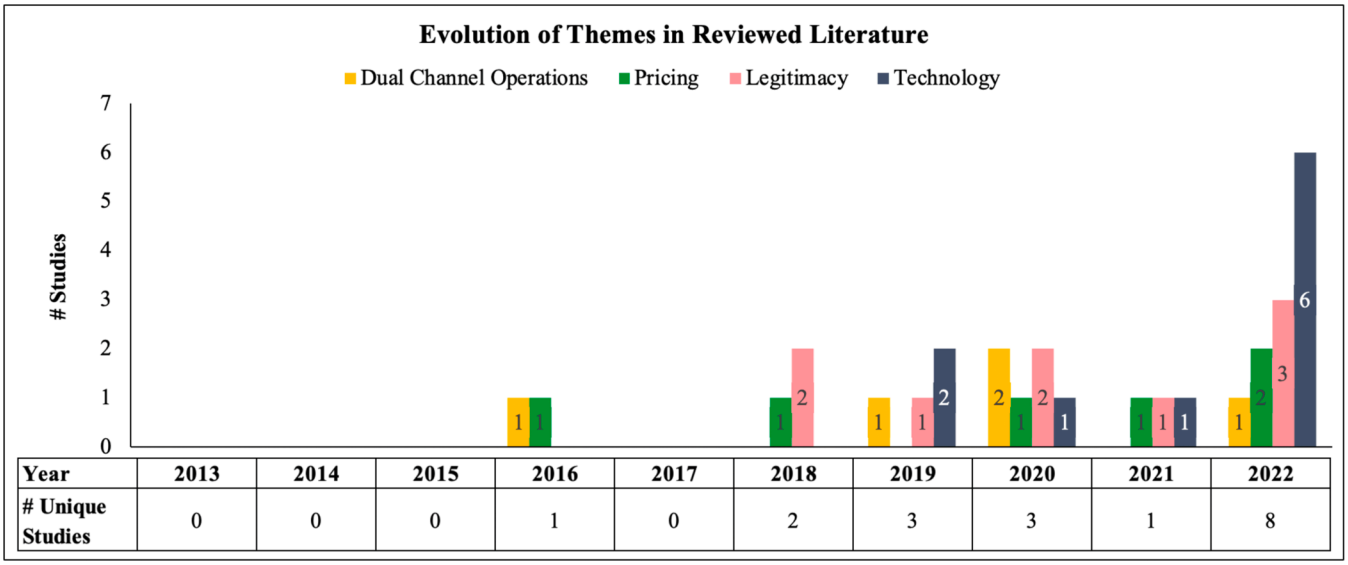

Fig. 2. Evolution of themes in reviewed literature.

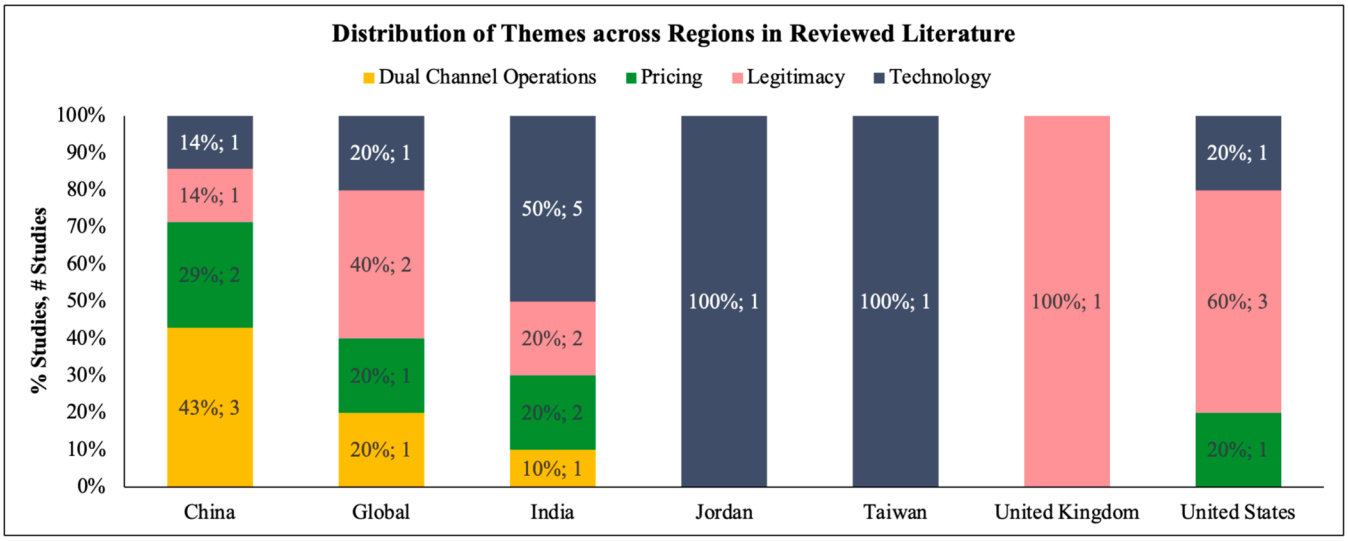

Fig. 3. Distribution of themes across regions in reviewed literature.

in regions and domains with minimal coverage.

3.4. Study types

A diverse range of study types, incorporating a mix of quantitative and qualitative analysis, were reviewed. Among the 18 papers, 10 employ quantitative analysis, including primary research, secondary research, and computational models; two studies utilise qualitative analysis, incorporating primary and secondary research, while six studies adopt mixed methods, combining both qualitative and quantitative analysis to provide comprehensive insights into the research context (see Table A5).

The more prevalent type of study we noticed is quantitative analysis. Among the ten studies reviewed, six are based on computational models that aim to optimise supply chain operations. This suggests a growing interest in leveraging advanced analytical techniques and data-driven solutions to enhance the efficiency and effectiveness of e-pharmacy supply chains. Using computational models provides valuable insights and practical strategies for improving various aspects of online pharmacies, such as inventory management, pricing, and shipment time prediction (see Table A6). While MMAT was used (see Table A7), certain conceptual and design-oriented contributions were qualitatively contextualised rather than numerically weighted, to preserve the richness and relevance of the findings. Summaries of insights from each paper are detailed in Table A8.

4. Results and analysis

4.1. Dual channel operations: Navigating the E-commerce surge in pharmacy sector

The rise of online pharmacies, propelled by the pursuit of convenience and the impact of the pandemic test the supply chain resilience, has been a defining trend within the pharmaceutical industry globally. As seen in Norway, the pandemic-triggered surge in pharmacy home deliveries overwhelmed supply chains, exposing capacity limits and triggering bullwhip-effect disruptions across food and pharmaceutical sectors [7]. Similarly, United Arab Emirates highlighted the significant shift, as in a study conducted one-third of respondents chose to order prescriptions from online pharmacies [27]. While in the United States, although Pharmacy Benefit Manager (PBM) have long-offered mail--order and local-delivery services, their market share remains low compared to brick-and-mortar pharmacies. However, in the recent years, increasing awareness, shifting customer preferences and evolving consumer behaviour are driving adoption. In response, even established entities like Walgreens are diversifying their operations to offer its customers a truly omnichannel experience. This includes maintaining a physical store presence, offering online services, and incorporating mail-order options into their repertoire with channel integration [28]. Leading industry players like Amazon in the US, Boots in the UK and Tokopedia in Indonesia to facilitate online prescription filling, drug pickup and doorstep delivery services [27]. Moreover, some EU countries have embraced cross-border e-prescription filling, signifying the widespread adoption of online pharmacy services [27].

The online pharmacy industry's dual-channel operation landscape is marked by multifaceted challenges that necessitate skillful operational management. These challenges include supply chain coordination, inventory pooling, distribution complexities, last-mile logistics and potential conflicts stemming from the integration of online and offline channels on top of fierce competition and complex price coordination [29]. Studies underscore the need for synergy-building between these channels, interoperability, aiming to improve overall efficiency and collaborative functionality. Strategies tailored to distinct customer segments across online and offline platforms are essential. Particularly as, younger customers lean towards online channels, while older individuals find value in traditional retail ones. Acknowledging this divergence and exploring differentiation in branding, packaging, and pricing strategies is crucial [29]. According to the theory of customer utility, demand in each channel is influenced by price differences, which also impacts procurement decisions for pharmacies implementing dual-channel pricing strategies [29].

Pharmaceutical retailers find themselves at a crossroads, a classic instance of channel conflict and channel substitution, as online channels witness a surge in revenue due to customer preferences, offline channels face declining revenues [29]. From a managerial perspective, it is critical for enterprises to acknowledge the competitive dynamics and substitutability inherent in dual-channel supply chains. Emphasising the need for effective supply chain coordination and an integrated omnichannel strategy. This not only optimises overall revenues from both online and offline avenues but also enhances supply chain agility in responding to rapid market shifts. To achieve stability and minimise uncertainties in managing dual-channel operations such as those caused by demand variability or the bullwhip effect, identifying equilibrium points between channel offerings becomes paramount [29].

Online pharmacies primarily operate in two business model typologies: proprietary Business to Consumer (B2C) online pharmacies,

handling end to end journey from transactions and service under one brand name, and third-party platform based B2C online pharmacies providing virtual platforms for individual traditional pharmacy vendors [16]. A study comparing two well-known Chinese online pharmacy companies, JD Pharmacy (third-party platform-based) and J1.com (proprietary), illustrates how these models reflect different supply chain network designs and service-level differentiation strategies. Customer sentiment for both models remains positive, aligning with customer utility theory, but the trade-offs are pronounced: J1.com excels in cost optimisation and packaging, offering an enhanced customer experience with attractive prices, but has slow logistics. In contrast, JD Pharmacy excels in delivery speed through its multiple warehouses, cross-docking strategies and direct distribution channels [16].

The global pandemic served as a stress test, catalysing supply chain resilience and driving innovation adoption within the sector. In China, the rapid implementation of quick response (QR) codes for offline medicine pick-up in response to online orders represents an agile solution to last-mile delivery challenges has proven to be a game-changer. This strategy not only reduces the risk of cross-infection but also safeguards patient privacy and risk management during the pandemic [30]. Furthermore, the adoption of 'online-to-offline' strategies has paved the way for enhanced distribution efficiency through decentralised logistics by leveraging the dense network of traditional retail pharmacy outlets. These strategies hold immense potential for advancing healthcare services with robust supply chain management [16,31].

4.2. Pricing strategies: balancing profitability and affordability

Empirical findings on online pharmacy pricing are closely tied to established SCM constructs. The bullwhip effect provides a useful lens: aggressive price promotions or sudden changes in demand (e.g., in response to public health crises) can amplify demand signals upstream, increasing supply chain volatility and operational costs [7,30]. For example, in the United States, while established platforms like GoodRx have long thrived in the online pharmacy space, the recent entry of Mark Cuban's Cost-Plus Drug Company brought heightened public attention to the prospect of cost-effective online medication sourcing [32]. However, for biologic medicines like insulin in the United States, manufacturing issues, distribution delays due to cold chain operations, process complexities, and the dominance of major biopharmaceutical companies: Novo Nordisk, Eli Lilly, and Sanofi drew insulin scarcity driving higher prices [33]. These impact both firm's profitability and end-users' affordability.

4.2.1. Profitability: the firm perspective

From a supply chain management perspective, online pharmacies have a clear price advantage due to their streamlined transaction channels, lower fixed costs due to the absence of brick-and-mortar spaces, fewer distribution layers than traditional retail pharmacies and economies of scale in digital fulfilment [16]. These efficiencies often translate to higher profit margins, as observed in the Chinese market, where operational savings enabled online pharmacies to maintain competitive pricing while achieving higher profit margins [16,31]. Resilience theory suggests that firms with agile pricing and robust digital infrastructure can better absorb demand shocks and sustain both profitability and affordability [7].

4.2.2. Affordability: the consumer perspective

Affordability in the online pharmacy sector is shaped by patients' out-of-pocket expenditures, which are influenced by reference pricing, the prevalence of generic medicines, and reductions in transaction and distribution costs. However, price elasticity remains variable across drug categories, with brand-name medications often remaining unaffordable for individuals with typical lower socioeconomic status (e.g., elderly and rural population) [31]. For example, in China, lowest-priced generic equivalents (LPGE) exhibited a mean affordability ratio of 0.84 compared to 2.5 for originator brands (OB), signaling that even online platforms may not resolve cost barriers for vulnerable groups such as the elderly or rural populations [31]. Furthermore, revealed that OBs were priced 14.6 times higher, while LPGEs were priced 3.4 times higher than the international reference price (IRP) [31]. It is important to note that the study had some limitations, including a small sample size and may not account for price fluctuations over time [31].

In the United States, rising drug prices are driving consumers are increasingly to seek lower prices from unregulated sources, highlighting risks for patient safety and access equity [32]. Particularly, chronic conditions like diabetes pose challenges for individuals in accessing affordable insulin, driving them to online pharmacies [33]. Among the 7 m diabetes patients in the US reliant on insulin, a quarter struggle with affordability, leading to risky outcomes like expired insulin administration, unstable glucose control, hospitalisation, and even death. Unfortunately, the demand for insulin has given rise to counterfeit products in the illegal market, attracting fraudulent organisations seeking higher profits [33].

Similar trend follows in India, a study conducted in Maharashtra, identified 56 % of participants (70 individuals) reported using online platforms to purchase medicines. Among these users, 86 % believed online services contribute to affordable healthcare, while 67 % expressed worries about counterfeit products [10].

As the pharmaceutical sector epitomises a credence goods market, where patients cannot directly assess product quality and must instead rely on signals of trust, such as regulatory oversight, transparent supply chains, and consistent pricing. Persistent information asymmetry amplifies these challenges. As evidenced in China, the United States, and India, pricing strategies not only shape consumer uptake of online pharmacies but also intensify concerns regarding legitimacy and patient safety [10,31–33].

4.3. Ensuring legitimacy and safety

Amid the COVID-19 pandemic, there has been a sharp rise in online medication purchases, offering cost savings and convenience. However, an alarming 2017 study by the US National Association of Boards of Pharmacy (NABP) found that nearly 96 % of online platforms selling prescription drugs were operating illegally. Worse, the World Health Organisation (WHO) estimates that over half of medications obtained from such sites, which conceal their addresses, are counterfeit. This urgent situation demands heightened awareness and robust measures to protect consumers from the dangers of illicit online pharmaceutical transactions [34]. Around 30,000 to 40,000 illicit online pharmacies are believed to be operational simultaneously, as reported by NABP [35].

According to WHO, substandard medicines are authorised medical products that fail to meet quality standards without the intention to deceive patients [36]. In contrast, falsified medicines are fraudulent products produced by unknown manufacturers under unregulated and unsanitary conditions, posing risks such as incorrect quantities of active pharmaceutical ingredients (API), contaminants, and mislabelling of identity and source. Counterfeit products encompass drugs that infringe the intellectual property or registered trademarks and include poor-quality medicines or those with intentional deceit. The term 'substandard/spurious/falsely labelled/falsified/counterfeit' (SSFFC) was introduced during the 70th World Health Assembly to establish a unified global definition and promote efforts to combat these medicines [36].

4.3.1. Deep dive into the challenges with SSFFC medicines on online pharmacies

The proliferation of illegal online pharmacies selling prescription drugs has drawn serious concern from the FDA, posing significant risks to Americans. The illegal sale of prescription drug stimulants not only jeopardises public health by contributing to potential abuse, misuse, and overdose but also underscores the broader issue of unregulated online

pharmaceutical transactions. Unfortunately, an increasing number of illicit online pharmacies are circumventing established prescription requirements, posing severe health risks [32].

These rogue pharmacies often traffic in counterfeit products manufactured in unsafe conditions, lacking active ingredients or containing hazardous substances. The pricing dynamics on these unapproved platforms, especially for essential drugs like insulin, are notably lower than legitimate sources. This stark pricing contrast raises concerns about the safety and authenticity of medications obtained through such channels. The challenge lies in the deceptive marketing strategies employed by these rogue pharmacies, making it difficult for consumers to distinguish between legitimate and illegitimate sources [16,32].

The prevalence of substandard and falsified medicines is a global concern affecting regulated countries and those with weaker systems. Falsified medicines are often driven by market demand, particularly for novel therapies like hormones, steroids, and supplements in high-income countries (HIC), as well as essential antimicrobials for diseases such as malaria, tuberculosis, HIV, and AIDS in low-to-middle-income countries (LMIC) [36].

Online pharmacies play a significant role in this context, with studies indicating that a substantial portion (67 % to 75 %) of web-based drug merchants operate illicitly [11]. Each year, approximately 10 % of pharmaceuticals are falsified, with half of these transactions occurring online due to weak regulatory systems [16,33]. Counterfeit medicines result in staggering financial losses, with an estimated $200 billion annual loss to the US pharmaceutical industry alone. Counterfeit drugs are also prevalent in other regions, with estimates suggesting that 30 % of medicines in Latin America, Africa, and Asia and 40–50 % of medicines in Pakistan are counterfeit. The complexity of pharmaceutical supply chains provides avenues for counterfeit drugs to infiltrate legitimate supply chains, presenting significant tracking and detection challenges [37].

India's prominence in the pharmaceutical industry contrasts with the challenge of counterfeit drugs originating from the country. Despite its global ranking as the third-largest producer of pharmaceuticals by volume and the 14th by value, around 75 % of counterfeit drugs worldwide originate from India [10].

4.3.2. Causes and implications of SSFFC medicine challenges

The causes of these challenges are multifaceted [37]. For substandard medicines, weak enforcement of Good Manufacturing Practices (GMP) and Good Distribution Practices (GDP) allows these medicines to enter legitimate chains [36,37]. Moreover, vaccine supply chains face inadequate transparency in monitoring cold chain temperature control, fraud involving expiry dates, counterfeit vaccines, and overall security issues. Mishandling of legitimate vaccines or delivering fake vaccines seriously threatens consumer safety [37]. Moreover, for psychiatric drugs, societal pressures, such as the stigma surrounding mental illness and cost considerations, may drive individuals to rely more on online pharmacies. This increased demand exposes patients to the high potential for drug abuse, as many online pharmacies facilitate transactions without requiring a prescription [3].

For counterfeit medicines, the deceptive resemblance of them to genuine ones necessitates rigorous content inspection for verification [36]. Consumer awareness is another concern. An Alliance for Safe Online Pharmacies (ASOP Global) survey revealed that 95 % of 500 US consumers were unaware of certification programs offered by the National Association of Boards of Pharmacy (NABP) to validate online pharmacy legitimacy [11]. This knowledge gap puts them at risk when dealing with illicit online pharmacies, jeopardising patient safety and the pharmaceutical supply chain's integrity. Moreover, some merchants operate multiple accounts, making distinguishing legitimate online pharmacies from illicit ones challenging due to the dynamic nature and vast scale of online platforms, making the creation of an exhaustive database nearly impossible [11].

4.3.3. A global challenge with practical evidences across different geographies

A recent survey in India shows that doorstep delivery, refill reminders and availability of substitute medicines are the top reasons for choosing online pharmacies. However, the delivery of the wrong medicines, authenticity and availability of the particular brand prescribed by doctors are key challenges [4].

In the United States, the formidable barriers posed by restrictive laws, clinic closures, and economic constraints have made accessing formal healthcare services daunting for pregnant women seeking abortions. Consequently, more individuals are turning to online pharmacies that offer abortion pills without a prescription. The allure of convenience, perceived self-agency, and privacy propels this trend [14]. In Texas, United States, many individuals seeking early pregnancy termination are turning to online pharmacies for medical abortions using mifepristone and misoprostol. This reflects a response to restrictive abortion laws, highlighting the role of online platforms amid legal constraints on traditional healthcare options [34].

Research discovered that procuring mifepristone and misoprostol pills online without a prescription is feasible, with around two-thirds of the products arriving within the stipulated shipping timeframe. However, the absence of instructions for use and the frequent divergence between the delivered products and the ordered brand remain concerning issues. Additionally, a substantial portion of the products (25 %) originate from India, and an intriguing observation emerges as multiple orders from distinct websites are traced back to a single vendor, identified through wire transfers to the same bank accounts [14].

Furthermore, only 30 % of orders contained active pharmaceutical products within 10 % deviation of the labelled dose, with the remaining shipments having inadequate amounts of active ingredients. Equally concerning is the discovery that 40 % of the products exhibited damaged packaging, and all suffered from minimal levels of active pharmaceutical ingredients, underscoring the vulnerability of subpar packaging to degradation [14]. The abrupt vanishing of some websites post-order placement triggered fraud alerts, putting financial information and billing addresses at risk [14].

Amidst the global rise of online pharmacies, regions like the European Union, the United States, and Canada have established regulatory frameworks, while Africa, especially Anglophone countries, shows progress. Ghana introduced a 2021 electronic pharmacy policy and a government-operated platform in 2022. Nigeria boasts mature regulations in the Pharmacy Council of Nigeria (Establishment) Act 2022, and the Online Pharmacy Regulations [38]. Rwanda and Kenya have their own regulations and guidelines, but refinement is needed in both content and implementation processes [38].

4.3.4. Strategies to minimise SSFFC medicines

Interpol's Operation Pangea successfully eliminated over 18,000 illegal online marketplaces, seizing unlicensed and counterfeit medicines exceeding $10.5 million (£6.5 million) by 2012. Operation Pangea has been highly effective in disrupting the illegal online trade of counterfeit and unlicensed medicines through coordinated international efforts in over 100 countries, significant seizures, and arrests. However, the persistent nature of this illicit trade, driven by low penalties and the ability of websites to relocate, underscores the need for ongoing vigilance, stronger legal frameworks, and public awareness to mitigate the risks to public health [39,40].

The issue of legitimacy in online pharmacies poses a significant challenge to patient safety and the pharmaceutical supply chain [37]. This situation calls for urgent regulatory measures to protect consumers from the dangers associated with unscrupulous online pharmacies [32]. Collaborative efforts and stringent regulations are essential to combat the prevalence of counterfeit medicines and ensure the integrity of the industry [39,40]. The link between illegitimate pharmacies and women's healthcare access highlights the broader implications of this issue [14,34]. Stricter oversight and consumer education are imperative

to address concerns about medication quality and safety [14]. By involving regulatory bodies, the WHO, and non-governmental organisations and enhancing regulations, stakeholders can collectively mitigate the risks posed by illicit online pharmacies and ensure the continued trustworthiness of the pharmaceutical supply chain [36,39,40].

A legitimate pharmacy, duly registered and tested, should instil consumer confidence. Public education on the risks of ordering medications online, especially when prices seem unusually low, is crucial. Even reputable platforms like GoodRx and Cost-Plus Drug Company are creating ambiguity for consumers. Global regulations are trailing the escalating problem. While awareness has increased, online pharmacies persist, and proactive efforts need to be improved. A risk-based approach and enhanced enforcement in the digital supply chain, informed by real-world evidence and post-market surveillance, are imperative given the challenge's magnitude [32].

Online pharmacy platforms can revolutionise medicine accessibility, filling the voids in traditional supply chains. The expansion and efficiency of these platforms rely on developing robust regulatory frameworks that carefully balance consumer protection and encourage innovation [38]. Initiatives by the US FDA, such as efforts to identify state-licensed online pharmacies and platforms like NABP's safe pharmacy, provide consumers with tools to authenticate the legitimacy of online pharmacies. This allows consumers to exercise vigilance when purchasing pharmaceutical products online, ensuring they are from valid and trustworthy sources [35]. Similarly, the European Union has implemented a robust legal framework under Directive 2011/62/EU to prevent falsified medicines from entering the legal supply chain. This includes the introduction of safety features on packaging, mandatory verification systems, and an obligatory logo to identify authorised online pharmacies, allowing EU consumers to verify legitimacy through national regulatory authority websites [41,42].

4.4. Transformative impact of technology on the pharmaceutical sector

The pharmaceutical sector has transformed due to technological advancements, revolutionising SCM, patient care, and accessibility. Corporate investments in robust information technology (IT) infrastructure have introduced innovative systems such as electronic data interchange (EDI), bar code systems (BCS), and enterprise resource planning (ERP). These technologies have not only reduced logistical costs but have also accelerated product development, enabling convenient doorstep pharmaceutical delivery and the emergence of online pharmacies [15].

In healthcare, the convergence of internet-driven pharmacy services with artificial intelligence (AI) capabilities has emerged as a powerful combination. AI-powered systems provide real-time clinical decision support, personalised medication reminders, and efficient inventory management, ultimately improving patient outcomes and medication adherence [30]. This successful implementation underscores the significance of digital solutions in meeting evolving patient and healthcare provider needs, ushering in a new era of efficient, accessible, and patient-centric care.

4.4.1. Technological innovations in patient care

India's "e-Aushadhi" web-based medicine SCM system for government-run stores is a notable example of technological intervention. This initiative addressed not only inefficiencies in drug warehouse management and logistics maintenance but also significantly improved generic drug prescriptions and awareness of free medicine facilities. Similar applications in the private sector witnessed notable improvements, with digital systems reducing holding stock by 50 % and saving up to an hour daily in restocking, resulting in reduced errors, enhanced stock accuracy, and inventory float. However, transitioning to digital systems brought its set of challenges, including technology interruptions and initial user resistance [43].

In Jordan, the widespread use of the internet prompted governments to adopt telehealth, resulting in the rise of tele-pharmacy services, particularly to mitigate COVID-19 transmission risks [44]. In response to the pandemic's urgency, the Internet Hospital Drug Delivery (IHDD) platform was developed and launched within just two weeks. This platform facilitated home delivery of medicines from Jordan University Hospital during lockdown. In the span of one month, the IHDD platform successfully delivered 28,494 medicines for 5994 prescriptions, with approximately half of them addressing chronic diseases [44]. Volunteers played a pivotal role in achieving an impressive service level, with just 0.25 % undeliverable prescriptions, 0.05 % improper drugs, and 0.03 % incorrect quantities. This pilot program showcased the potential of technology-driven healthcare initiatives during crises, emphasising community pharmacy services' effectiveness [44].

The successful IHDD platform implementation highlighted the value of digital solutions in enhancing healthcare services, particularly during crises. Telehealth and tele-pharmacy not only improve patient accessibility but also provide a glimpse into the future of healthcare delivery, underlining the need to invest in such innovative solutions [44]. This reflects the global interest and feasibility of integrating technology into healthcare services.

Similarly, there has been a notable surge in adopting innovations that facilitate convenient remote access to health products and services. Online pharmacies, functioning as intermediaries, distributors, or retailers, utilise digital technology to streamline the distribution of health supplies. Serving as a bridge, they connect remote and underserved populations to essential medicines, eliminating the need for patients to endure long waiting hours or queues. This model has rapidly gained traction in many low-and-middle-income countries, particularly in Africa, driven by increasing smartphone adoption and internet penetration rates, heralding a digital renaissance in healthcare. Over 160 innovators are contributing to the growth of online pharmacy solutions [38].

4.4.2. Technological innovations in delivery of medicines

A significant advantage of online pharmacies lies in democratising access, especially in traditionally excluded regions. Notably, mPharma provides access to affordable, high-quality medicines for over 2 million Africans across Ghana, Nigeria, Kenya, Zambia, and Zimbabwe. MyDawa, Kenya's pioneering registered online pharmacy, offers a direct-to-consumer web platform with quality controls across the entire supply chain, enabling consumers in remote, underserved communities to conveniently access and receive deliveries of health supplies at affordable prices [38].

This digital shift is not limited to online startups; traditional retail pharmacies also embrace the model. HealthPlus, a well-established pharmacy chain with 62 locations across Nigeria, has launched an integrated digital platform. Leveraging its existing retail operations, it provides patients with online pharmacy, telemedicine, and diagnostics services [38]. Moreover, in Bangladesh, telemedicine services have bridged infrastructure gaps by enabling rural patients to consult urban doctors, allowing more than 80 % pharmacy owners believe in fulfilment of equitable medical services to remote populations [45].

In Bangladesh, there has been a rise in tele-pharmacist consultation services aimed at assisting customers with inquiries related to COVID-19 equipment instructions and protocol management [45]. However, in Norway, pre-pandemic contingency plans proved generally inadequate for managing disruptions of the scale and duration [7].

The COVID-19 pandemic prompted the emergence of e-pharmacies in some nations while posing challenges for others. In India, it significantly impacted e-pharmacy supply chains, leading to service disruptions and necessitating innovative solutions for Netmeds, a major Indian e-pharmacy, service level attainment dropped by 11 %, with delays in last-mile logistics exceeding two days during the pandemic [46–48].

Integration of Machine Learning (ML) based mathematic models improved post-lockdown service level from 63 % to 94 %, enabling accurate shipment time forecasts, reduced inventory costs and improved

supply chain resilience [46,47]. These advanced technologies offer e-pharmacy opportunities to strengthen supply chains, enhance customer satisfaction, and optimise business performance during and beyond the pandemic [46]. They also enhance stakeholder management, enabling timely interventions for process delays, and ultimately boosting operational efficiencies and competitiveness [47]. Although the study draws on data from over 6 million shipments, its applicability to global e-pharmacy supply chains is limited due to unique country-specific restrictions [47].

4.4.3. Technological innovations driving growth in online pharmacies

Traceability technology, employing tools like RFID, NFC, or barcodes on medicines, ensures product quality, safety, and consumer protection. The Central Verification Register (CVR) enhances credibility by enabling precise tracking, utilising data matrices to trace pharmaceutical products from supplier to dispenser, thereby deterring counterfeit product entry into supply chains [33]. To harness the potential of web-based SCM, a standardised approach to stock maintenance and logistics is recommended. Developing clear standard operating procedure (SOPs) for logistics management streamlines operations and ensures a seamless transition, optimising efficiency, accuracy, and transparency in medicine distribution and procurement [43].

The implementation of computerised inventory programs has proven highly effective in optimising product availability and minimising shortages. Notably, visual attention significantly influences customer demand, with larger tiles and prominent website visuals capturing more attention, resulting in increased customer engagement and higher purchase likelihood. Online pharmacies have leveraged this technology to craft visual attention-driven marketing strategies, aligning them with product inventory. This approach has demonstrated improved profitability compared to traditional methods like 'high-profit items first' and 'best-seller items first'. Additionally, this strategy supports sustainable development by reducing resource and energy wastage from excessive inventory holdings [49].

In parallel, website analytics have evolved significantly, employing mathematical algorithms and frameworks to predict illicit online pharmacies by analysing website traffic and engagement data through search engine optimisation (SEO) techniques. While these strategies offer autonomy to customers, there are challenges regarding the depth of traffic analysis, accuracy assessment, and potential improvements in the prediction framework [11].

The increasing popularity of online pharmacies has prompted concerns about data privacy [4,10,48]. Leading the Union Health Ministry in India to consider regulations and strict actions against e-pharmacies [48]. This move is in response to worries regarding the safety and efficacy of drugs sold online, especially in the absence of robust regulatory mechanisms. Notable pharmacy apps, including Tata 1 mg, Amazon, Flipkart, NetMeds, MediBuddy, Practo, and Apollo, received show-cause notices from the Drugs Controller General of India (DCGI) in February 2023 for alleged violations of norms in the online sale of drugs. The DCGI had previously issued orders to all states and Union Territories in May and November 2019, reiterating the need for compliance with government norms [48].

4.4.4. Barriers and limitations of technology adoption in pharmaceutical SCM

Despite widespread optimism about the transformative potential of artificial intelligence in pharmacy, real-world adoption is constrained by critical resource and infrastructure barriers [29,50]. As recent survey research from Ethiopian community pharmacies shows, even when pharmacists have positive perceptions and strong willingness to adopt AI, implementation is often stymied by the lack of reliable internet access, insufficient AI-specific software and hardware, limited training, and high running costs [50]. Over 80 % of pharmacists surveyed identified these challenges as major obstacles, highlighting that successful scaling of digital innovations requires not just technological readiness but also investments in infrastructure, policies, data interoperability and workforce development to ensure equity and sustainability especially in LIMC [10,50].

Blockchain systems especially those using energy-intensive consensus mechanisms can raise significant operational costs, environmental concerns, as applications also require miners to run the program efficiently, challenging both cost-to-serve and sustainability goals [10]. The risk of vendor lock-in is also pronounced, as pharmaceutical firms may become dependent on closed, proprietary systems, undermining supply chain flexibility and adaptability in rapidly evolving markets [10, 37].

5. Discussion

This section summarises the overall analysis and explores interlinks between themes and early pieces of evidence on addressing the challenges discussed throughout this review. As summarised in following diagram (see Fig. 4), these themes highlight the challenges and opportunities that define the evolving online pharmacy landscape. Each theme touches on critical aspects of supply chain management, regulatory frameworks, and technological advancements, and their intersections point to the complexities of balancing innovation with safety and regulation.

5.1. Contextualising the key findings

The integration of technology within the SCM of online pharmacies has reached a significant level of maturity, encompassing technologies such as EDI, ERP, inventory management systems, and internet-based operations. However, the application of AI/ML to optimize and enhance these operations is a relatively recent development, as indicated by recent research [30,46,47]. While these applications show promising enhancements to existing systems, there is still a need to explore the long-term implications of their adoption.

As discussed in the previous sections, the rise of online pharmacies has coincided with a troubling surge in illicit platforms distributing SSFFC drugs, posing serious risks to patient health [11]. Solutions that employ technological analysis of online pharmacy credibility based on web traffic and engagement data have emerged. However, these solutions have limitations concerning data availability and algorithm accuracy, rendering them temporary and less accurate in addressing the problem effectively.

Recent research has focused on implementing blockchain technology frameworks through regulatory body monitoring and public-private partnerships to ensure legitimate activities within online pharmacy operations [10,37]. These frameworks have shown efficiency and reliability, but the challenges and implications of their real-world implementation and the training and education required for supply chain actors to adopt them remain unexplored. Furthermore, addressing resistance to change is a crucial aspect that needs investigation. Primary research and pilot testing of specific technological applications are imperative to answer these complex questions.

5.2. Recommendations

Drawing upon the outcomes of the thematic analysis, the following actionable recommendations have been formulated to enhance the SCM capabilities within the realm of online pharmacies.

5.2.1. Change management and training for seamless adoption

Transitioning from manual record-keeping to digital platforms, particularly with the introduction of technologies like blockchain, requires careful change management and thorough training. Drawing from the challenges faced by the Indian government in implementing "e-Aushadhi" web-based medicine SCM technology [43], online pharmacies should prioritise comprehensive training programs for their supply

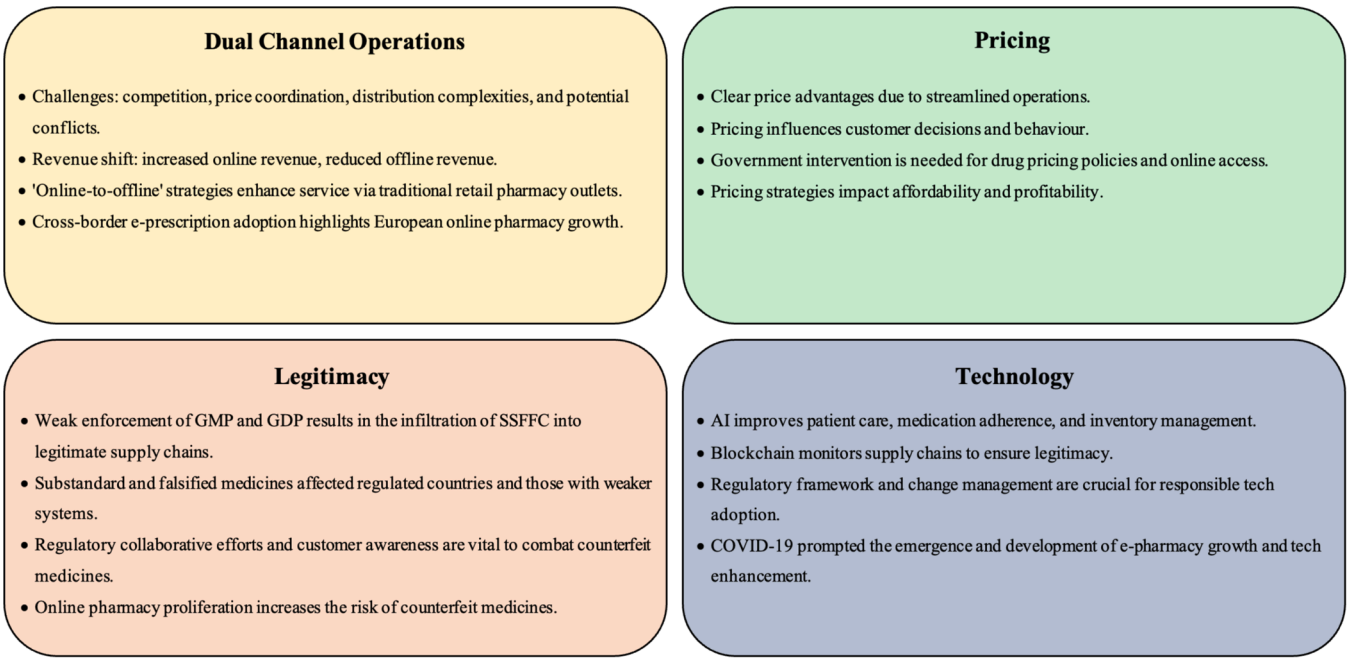

Fig. 4. Key Insights from the thematic analysis.

chain actors. This will facilitate smoother transitions, mitigate resistance to change, and enable efficient utilisation of advanced solutions.

5.2.2. Assessment of long-term effects of AI/ML

The integration of AI and ML in online pharmacy supply chains is relatively new, highlighting the need for a focused examination of their long-term effects. As delivery reliability and strong relationships with customers and suppliers are essential for long-term supply chain resilience and success [7]; industry players, researchers, and policymakers should engage in comprehensive technological research to ensure sustained effectiveness. By exploring the extended implications of AI/ML, stakeholders can gain insights into how these technologies can reshape supply chain dynamics over time and lead to strategic advancements in the field.

5.2.3. Development of a holistic regulatory framework

The evolving landscape of online pharmacies, often operating within weak regulatory systems [33], demands a robust regulatory framework. The infusion of technology has transformed online pharmacies, addressing critical challenges through innovative solutions such as AI-powered systems and blockchain technology [10,30,37,44]. A comprehensive regulatory framework is needed to address multifaceted challenges such as legitimacy, patient safety, data privacy, and preventing counterfeit medicines. Policymakers should collaborate extensively with industry stakeholders to establish guidelines that ensure responsible and secure online pharmaceutical practices.

5.2.4. Government intervention in drug pricing policies

Persistent disparities between online medicine prices and international reference prices (IRP) highlight the urgent need for robust government intervention in digital pharmacy markets. For example, a study in China found that medicines on online platforms were priced 3.4 to 14.6 times higher than the IRP, underscoring the risk of unaffordable access and potential price gouging [31]. To address this, national health authorities should implement reference pricing policies for essential drugs sold online, establishing maximum allowable markups relative to the IRP. Such policies would promote price transparency, curb excessive margins, and ensure equitable access, especially for vulnerable populations and LMICs. This is essential to address the complex interplay between high prices, scarcity of medicines, and the rise of counterfeit products in the illegal market [33]. Well-crafted pricing strategies and regulatory measures are crucial for maintaining a balanced and sustainable online pharmacy ecosystem.

5.2.5. National authority led credibility assessment and consumer awareness

The proliferation of illicit online pharmacies, such as the up to 40,000 identified by the NABP in the United States, with 96 % of online platforms selling prescription drugs operating illegally demands a multifaceted response centered on technology and public engagement [34,35]. To enhance legitimacy and safeguard patient safety, policymakers should mandate the adoption of advanced credibility assessment technologies, such as blockchain-enabled product verification and track-and-trace systems. These solutions offer end-to-end supply chain transparency, enabling real-time authentication of medicines and the identification of unauthorised actors.

Simultaneously, national regulatory bodies should invest in sustained consumer awareness campaigns and escalation mechanisms leveraging digital platforms, certification logos, and public service announcements to educate patients on how to identify and verify legitimate online pharmacies. By combining technological safeguards with targeted outreach, stakeholders can significantly reduce the circulation of counterfeit medicines and empower consumers to make safer, more informed choices in digital health markets.

6. Conclusion

This review provides a comprehensive state-of-the-art synopsis of the multifaceted online pharmacy landscape, describing the sector's dual-channel operations, pricing strategies, legitimacy challenges, and technological advances. The insights underline the need for strategic coordination in dual-channel operations, balanced pricing approaches, robust regulatory measures to ensure legitimacy and patient safety, and careful oversight of technology's transformative potential. This highlights the collective efforts required to shape a secure, efficient, and innovative online pharmacy landscape for the benefit of patients and industry stakeholders.

Our theme-based narrative review explores existing research on SCM

of online pharmacies published between 2013 and 2022 (with some coverage of newer literature too) and acknowledges the increase in research activity in this space paving a guide to future research. We speculate that this research topic is still in an embryonic phase with the existing studies including a broad spectrum of study types: primary research, secondary research, case study-based analysis and even novel contributions through simulated computational models all discussing various approaches to tackle current challenges faced by the online pharmacies industry with limited evidence to its long-term implications and sustainability.

Despite the study's strengths in offering a structured, contextually rich synthesis of the recent literature on online pharmacy supply chains, it suffered from a few limitations that should be acknowledged. First, the literature search was conducted exclusively in Scopus, which may have led to the exclusion of relevant studies indexed in databases such as Web of Science, PubMed, or IEEE Xplore. Second, although systematic literature review principles were applied, the protocol was not preregistered, which may affect transparency and reproducibility. Third, while thematic categorisation was rigorously conducted by dual reviewers and an examiner, some subjectivity may persist in the interpretation and classification of themes. Moreover, the relatively small final corpus of 18 studies constrains statistical generalisability. As the field matures, future reviews should seek to include larger and more representative samples, employ standardised quality appraisal tools, use formal coding validation metrics (such as Cohen's κ), and adopt triangulated analytical methods to strengthen reliability, breadth of insight, and overall methodological rigor.

This study contributes to a foundational understanding of the regulatory, technological, and logistical complexities within online pharmacy supply chains and emphasises the urgency for coordinated regulatory oversight. Looking ahead, future research could benefit from sub-categorical analysis within each thematic pillar and deeper integration of primary data. Comparative studies exploring dual-channel operations across diverse regulatory regimes, including under-examined contexts such as Europe, remain a key priority. There is also considerable scope for interdisciplinary research integrating criminology and digital-trust theory to address issues such as dark-web sourcing, payment processor enforcement, and cyber-crime deterrence. Given the rapidly evolving technological landscape, future work should benchmark emerging technologies like blockchain against established track-and-trace systems (e.g., GS1 EPCIS, SNOMED) to better inform adoption and policy. These avenues hold significant promise for advancing both scholarly knowledge and industry practice in support of safe, equitable, and resilient online pharmaceutical supply chains.

CRediT authorship contribution statement

Sai Krishna Pabba: Writing – review & editing, Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Astha Verma:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Alexandros Nikitas:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Validation, Conceptualization. **Radi Haloub:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table A1
List of journal articles included in this review.

Journal	# Articles
Asia Pacific Journal of Health Management	1
BMC Medical Informatics and Decision Making	1
Contraception	1
Drugs and Therapy Perspectives	1
Frontiers in Pharmacology	1
Health Policy and Technology	1
IEEE Transactions on Computational Social Systems	1
International Journal of Environmental Research and Public Health	2
International Journal of Physical Distribution and Logistics Management	1
International Journal of Recent Technology and Engineering	1
Journal of Medical Internet Research	1
Journal of Pharmaceutical Negative Results	1
National Journal of Community Medicine	1
Processes	1
Psychiatry Research	1
The International Journal of Logistics Management	1
The Pharmaceutical Journal	1

Table A2
List of authors of journal articles included in this review.

Authors (Author ID)	# Articles	Authors (Author ID)	# Articles	Authors (Author ID)	# Articles
Abdeljalil, Mariam	1	Huang, Taomin	1	Raymond, Elizabeth G.	1
Al-Ansari, Tareq	1	Jain, Vipin	1	Rehman, Muhammad	1
Al-Manaseer, Bayan	1	Javed, Ibrahim Tariq	1	Sarkale, Sandeep L.	1
Arya, Satyendra	1	Jeon, Gwanggil	1	Shi, Victor	1
Bu, Fengjiao	1	Jiang, Xiaoyan	1	Singh, Deepnshu	1
Chaddah, Jyotinder Kaur	1	Kerbache, Laoucine	1	Sun, Hong	1
Chang, Yu-Cheng	1	Kumara, Soundar	1	Tang, Fengmin	1
Chen, Yan-Kwang	1	Li, Ling	1	Theivendren, Panneerselvam	1
Chen, Zhitong	1	Lim, Ming K.	1	Umbrkar, Sheetal	1
Cheng, Yan	1	Liu, Jingfang	1	Venkataraman, Yegnanarayanan	2
Chiu, Fei-Rung	1	Manaseer, Qusai	1	Wang, Fan	1
Coeytaux, Francine	1	Margaria, Tiziana	1	Wang, Hongjuan	1
Devi, Kanniga	2	Mariappan, Mahesh Babu	2	Wang, Qingyu	1
Dhanusu, Subusri	1	Mishra, Sandeep	1	Wells, Elisa	1
Fosso Wamba, Samuel	1	Monteith, Scott	1	Winikoff, Beverly	1
Gao, Zhongli	1	Mu, Yuan	1	Yan, Jingchao	1
Ghanem, Naira	1	Mulla, Zameerahmed S.	1	Yang, Yue	1
Glenn, Tasha	1	Murtagh, Chloe	1	Ye, Zhengqiang	1
Gupta, Rajeev	1	Muthupandi, Sowmyasri	1	Zhang, Wei	1
Haji, Mona	1	Naidu, Jigisha	1	Zhang, Xiuwen	1
Hammour, Khawla Abu	1	Pande, Bhanupriya Shivshankar	1	Zhao, Hui	1
Hou, Yanhong	1	Qureshi, Kashif Naseer	1	Zhou, Yingyi	1

Table A3
Study themes of journal articles included in this review.

Theme	Studies (n)	*Reference*
Dual Channel Operations	5	*Bu* et al., *2022; Hou* et al., *2020; Jain, Arya and Gupta, 2019; Liu* et al., *2020; Wang* et al., *2016*
Pricing	6	*Haji, Kerbache and Al-Ansari, 2022; Liu* et al., *2020; Murtagh* et al., *2018; Sarkale* et al., *2022; Singh and Chaddah, 2021; Wang* et al., *2016*
Legitimacy	9	*Ghanem, 2019; Haji, Kerbache and Al-Ansari, 2022; Liu* et al., *2020;*
Technology	10	*Monteith and Glenn, 2018; Murtagh* et al., *2018; Rehman* et al., *2022;* *Sarkale* et al., *2022; Singh and Chaddah, 2021;* *Zhao, Muthupandi and Kumara, 2020;* *Bu* et al., *2022; Chen, Chiu and Chang, 2019; Hammour* et al., *2022;* *Jain, Arya and Gupta, 2019; Mariappan* et al., *2022a; Mariappan* et al., *2022b; Pande, Mishra and Dhanusu, 2022; Rehman* et al., *2022; Singh and Chaddah, 2021; Zhao, Muthupandi and Kumara, 2020;*

Table A4
Study locations of journal articles included in this review.

Study Location	Studies (n)	*Reference*
China	3	*Bu et al., 2022; Liu et al., 2020; Wang et al., 2016*
Jordan	1	*Hammour et al., 2022*
India	6	*Jain, Arya and Gupta, 2019; Mariappan et al., 2022a; Mariappan et al., 2022b; Pande, Mishra and Dhanusu, 2022; Sarkale et al., 2022; Singh and Chaddah, 2021*
Taiwan	1	*Chen, Chiu and Chang, 2019*
United Kingdom (global context)	1	*Ghanem, 2019*
United States	3	*Monteith and Glenn, 2018; Murtagh et al., 2018;*
Internationals	3	*Zhao, Muthupandi and Kumara, 2020*
Funded by Qatar	(1)	*Haji, Kerbache and Al-Ansari, 2022*
Authors from Qatar and France	(1)	*Hou et al., 2020*
Funded by China	(1)	*Rehman et al., 2022*
Authors from China, France and Canada		
Funding information unavailable		
Authors from Pakistan, Canada, Ireland and South Korea		

Table A5
Study type of journal articles included in this review.

Study Type	Studies (n)	*Reference*
Quantitative Analysis	10	*Chen, Chiu and Chang, 2019; Hou et al., 2020; Mariappan et al., 2022a;*
Qualitative Analysis	2	*Mariappan et al., 2022b; Monteith and Glenn, 2018; Murtagh et al., 2018;*
Mixed Method	6	*Rehman et al., 2022; Singh and Chaddah, 2021; Wang et al., 2016;*
		Zhao, Muthupandi and Kumara, 2020
		Ghanem, 2019; Pande, Mishra and Dhanusu, 2022
		Bu et al., 2022; Haji, Kerbache and Al-Ansari, 2022; Hammour et al., 2022;
		Jain, Arya and Gupta, 2019; Liu et al., 2020; Sarkale et al., 2022

Table A6
Study details of articles included in this review.

Reference	Research objective
Bu et al., 2022	Case study comparing at-home prescription delivery vs self-pick-up – qualitative and quantitative analysis performed
Chen, Chiu and Chang, 2019	Computational model based on inventory linked website visuals
Ghanem, 2019	Secondary research - theoretical study
Haji, Kerbache and Al-Ansari, 2022	Survey - qualitative and quantitative analysis-based insights
Hammour et al., 2022	A case study evaluating efficiency of online pharmacy in Jordan – qualitative and quantitative analysis performed
Hou et al., 2020	Computational model-based analysis to analyse dual operations
Jain, Arya and Gupta, 2019	Primary research - survey conducted with analytical and descriptive elements
Liu et al., 2020	Case study comparing customer reviews of two online pharmacy operating models – qualitative and quantitative analysis performed
Mariappan et al., 2022a	Novel computational model to predict shipment time
Mariappan et al., 2022b	Novel computational model to predict shipment time
Monteith and Glenn, 2018	Secondary research based on content on online pharmacies websites
Murtagh et al., 2018	Primary research - testing and evaluation of shipment time and quality of drugs procured online
Pande, Mishra and Dhanusu, 2022	Primary research - group discussions based on qualitative analysis
Rehman et al., 2022	Novel computational model based on blockchain to improve drug regulatory authority control on value chain
Sarkale et al., 2022	Primary research – survey (statistical analysis) and secondary research – newspapers, websites, and magazines
Singh and Chaddah, 2021	Primary research – survey (correlation data analysis)
Wang et al., 2016	Secondary research - analyses the availability and affordability of drugs performed as per WHO and HAI guidelines
Zhao, Muthupandi and Kumara, 2020	Novel framework and computational model

Table A7
Mixed Methods Appraisal Tool (MMAT) Evaluation of Reviewed Articles.

Category of study designs	**Methodological quality criteria**	*Bu et al., 2022*	*Chen, Chiu and Chang, 2019*	*Ghanem, 2019*	*Haji, Kerbache and Al-Ansari, 2022*	*Hammour et al., 2022*	*Hou et al., 2020*	*Jain, Arya and Gupta, 2019*	*Liu et al., 2020*	*Mariappan et al., 2022a*	*Mariappan et al., 2022b*	*Montieth and Glenn, 2018*	*Murtagh et al., 2018*	*Pande, Mishra and Dhanusu, 2022*	*Rehman et al., 2022*	*Sarkale et al., 2022*	*Singh and Chaddah, 2021*	*Wang et al., 2016*	*Zhao, Muthupandi and Kumara, 2020*
Screening questions (for all types)	S1. Are there clear research questions?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	S2. Do the collected data allow to address the research questions?	Yes	N/A	No	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
1. Qualitative	1.1. Is the qualitative approach appropriate to answer the research question?	Yes	N/A	Yes	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A
	1.2. Are the qualitative data collection methods adequate to address the research question?	Yes	N/A	N/A	Yes	Can't tell	N/A	Yes	Yes	N/A	N/A	N/A	N/A	Yes	N/A	Can't tell	N/A	N/A	N/A
	1.3. Are the findings adequately derived from the data?	Yes	N/A	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A
	1.4. Is the interpretation of results sufficiently substantiated by data?	Yes	N/A	Yes	Yes	Yes	N/A	Yes	Yes	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A
	1.5. Is there coherence between qualitative	Yes	N/A	N/A	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	Yes	N/A	Yes	N/A	N/A	N/A

(*continued on next page*)

Table A7 (*continued*)

	data sources, collection, analysis and interpretation?																		
4. Quantitative descriptive	4.1. Is the sampling strategy relevant to address the research question?	Yes	N/A	N/A	Can't tell	Can't tell	N/A	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes
	4.2. Is the sample representative of the target population?	Can't tell	N/A	N/A	No	No	N/A	Yes	Yes	Yes	Yes	Yes	Yes	N/A	N/A	Yes	Yes	Yes	Yes
	4.3. Are the measurements appropriate?	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes
	4.4. Is the risk of nonresponse bias low?	Can't tell	N/A	N/A	Yes	Yes	N/A	Can't tell	Yes	Yes	Yes	N/A	Yes	N/A	Yes	Can't tell	Yes	Yes	Yes
	4.5. Is the statistical analysis appropriate to answer the research question?	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	Yes	Yes	Yes	Yes	Yes
5. Mixed methods	5.1. Is there an adequate rationale for using a mixed methods design to address the research question?	N/A	N/A	N/A	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	Can't tell	N/A	N/A	N/A
	5.2. Are the different components of the study effectively integrated to answer the research question?	Yes	N/A	N/A	Yes	Yes	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A

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Table A7 (*continued*)

	5.3. Are the outputs of the integration of qualitative and quantitative components adequately interpreted?	Yes	N/A	N/A	Yes	Yes	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A
	5.4. Are divergences and inconsistencies between quantitative and qualitative results adequately addressed?	N/A	N/A	N/A	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	No	N/A	N/A	N/A
	5.5. Do the different components of the study adhere to the quality criteria of each tradition of the methods involved?	Yes	N/A	N/A	Yes	N/A	N/A	Yes	Yes	N/A	N/A	N/A	N/A	N/A	N/A	Yes	N/A	N/A	N/A

Table A8
Summary of insights of articles included in this review.

Reference; Country	Journal	# Citations	Theme	Considerations	Key Findings	Limitations	Additional Insights
Bu et al., 2022; China	Frontiers in Pharmacology	1	Dual Channel Operations and Technology	Integration of AI with internet-based hospital pharmacy services shown promising outcome in health care delivery.	AI-based internet hospital pharmacy service ensures safe, rational drug use, saves time and costs, and is crucial for COVID-19 prevention.	AI system needs improvement in language accessibility, support for elder patients, and regular maintenance.	QR codes for offline self-pick-up are highly effective, preferred by 86 % of patients, reducing infection risks during the pandemic.
Chen, Chiu and Chang, 2019; Taiwan	International Journal of Environmental Research and Public Health	15	Technology	Inventory linked to visual attention drives cost optimisation. Prominent visuals and larger tiles on a website increase engagement and boost purchase likelihood.	The model optimises online pharmacies' profits, surpassing traditional methods, and promotes environmental sustainability by reducing waste.	The proposed model should incorporate price elasticity and space elasticity to enhance accuracy.	The need to consider inventory shortage losses alongside unsold inventory to improve decision-making during significant demand variability was emphasised.
Ghanem, 2019; United Kingdom	The Pharmaceutical Journal	17	Legitimacy	Good distribution and manufacturing practices deemed important to eliminate falsified and substantial medicines.	The lack of global harmonisation of quality assurance and surveillance led to substandard drug production and enter the supply chain.	More insights into economic status and regional context is essential to address this globalised problem with localised solution.	Patient awareness and education is even more essential with online pharmacies to minimise access to poor quality medicines.
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Haji, Kerbache and Al-Ansari, 2022; International	Processes	4	Legitimacy and Pricing	Monopolistic behaviour of insulin providers and process complexities cause delays and supply shortages driving price pressure and illicit activities.	Analysing survey questionnaire, semi-structured interviews and literature searches traceability is important to ensure maximum safety of insulin.	Limited access to data and medical staff to interview as the study was conducted during the pandemic.	Pharmaceutical companies and stakeholders have shown interest in developing strategies to maximise patient safety when purchasing insulin.
Hammour et al., 2022; Jordan	Health Policy and Technology	10	Technology	In Jordan, online pharmacy platform was built and deployed within two week in the start of lockdown and used to supply drugs primarily for chronic diseases.	The platform demonstrated the value of harnessing digital solutions to enhance healthcare services, especially in times of crisis.	The study was conducted based on pandemic response online pharmacy that operated for one month in Jordan by a hospital, limiting generalisability.	Telehealth and tele-pharmacy efficiently administered drugs, benefiting patients with chronic illnesses and mobility constraints.
Hou et al., 2020; International	International Journal of Environmental Research and Public Health	7	Dual Channel Operations	Dual-channel approach: challenges include cross-selling, customer/ resource competition, and channel conflicts as online/offline vie for market share.	Coordination between online and offline operations is crucial for maximising profits and providing a seamless customer experience.	The lack of detailed quantitative analysis and empirical testing is a significant limitation.	Targeting different customer segments for online and offline channels is essential for effective marketing and customer satisfaction.
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Jain, Arya and Gupta, 2019; India	International Journal of Recent Technology and Engineering	3	Dual Channel Operations and Technology	Integration of SCM and information technology has been beneficial for online pharmacies.	The survey results show discounted prices, doorstep delivery, and medicine reminder services, increased user convenience.	The research's geographical scope is limited to the western part of Uttar Pradesh in India, limiting its generalisability.	Proliferation of IT infrastructure has revolutionised the pharmaceutical industry, spurred the growth of online pharmacies.
Liu et al., 2020; China	BMC Medical Informatics and Decision Making	41	Dual Channel Operations, Legitimacy and Pricing	In China, there are 2 online pharmacy operating models - proprietary B2C and third-party-platform based B2C operations.	Proprietary B2C model is able to achieve cost optimisation and packaging but lacks logistic speeds compared to third-party-platform.	This study is limited to China comparing detailed operations of only two most online pharmacies with different operating strategies.	Pharmacies started to operate in both online and offline platforms leading to operational and pricing challenges. 'online-to-offline' strategy is efficient.
Mariappan et al., 2022a; India	International Journal of Physical Distribution and Logistics Management	4	Technology	Shipment time prediction using pre-COVID and post-COVID lockdown data from an e-pharmacy in India.	ML solution shows 49 % improvement (post-COVID) and 24 % improvement (pre-COVID) in shipment time estimate compared to logistic provider.	The study is limited one of the India's largest e-pharmacy and does not predict medicine order processing time.	Shipment time estimates are valuable for planning and optimisation of therapeutics, diagnostics, and vaccines delivery.
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Mariappan et al., 2022b; India	The International Journal of Logistics Management	14	Technology	Predicting shipment times of therapeutics, diagnostics, and vaccines during the COVID-19 pandemic using AI/ML approach in India.	AI/ML prediction engine improved shipment time accuracy to 93.5 %, traditionally 63 % enhancing service level and customer satisfaction in e-pharmacy supply chains.	The study's scope is limited to the Indian context, making generalisation to global e-pharmacy supply chains challenging due to unique restrictions in each country.	ML-based solutions enable timely intervention measures, boosting operational efficiencies and competitiveness in e-pharmacy supply chains.
Monteith and Glenn, 2018; US	Psychiatry Research	28	Legitimacy	In the US, High out-of-pocket costs led to international online purchases. Although illegal, law enforcement is lax due to the small	Patient searching online to buy prescribed psychiatric drugs is commonly presented with rouge pharmacies.	Illicit behaviour of Online pharmacies was verified based on certification status, no drugs were purchased or tested.	Societal pressures like cost, stigma and the evolving role of patients drive e-buying; patient education about drug buying is essential.

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Table A8 (*continued*)

Reference; Country	Journal	# Citations	Theme	Considerations	Key Findings	Limitations	Additional Insights
				package delivery tracking challenge.			
Murtagh et al., 2018; US	Contraception	63	Legitimacy and Pricing	Obtaining abortion pills without prescription is feasible in the US; people prefer for the convenience, perceived self-agency and privacy.	Of the 20 orders placed in different online pharmacies, only 2/3rd of the products arrived within the advertised shipping time and had within 8 % labelled active ingredient.	Only 20 online pharmacies in the US were studied and only one tablet from each chemical assay was tested for active ingredients.	The products that appeared were rarely the same brand as ordered, and one-fourth were shipped from India.
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Pande, Mishra and Dhanusu, 2022; India	National Journal of Community Medicine	-	Technology	Digitalisation challenges outweigh benefits in India, due to poor transitioning protocols.	Web-based drug warehouse system can significantly reduce manual errors, increase stock maintenance quality, and prevent stock-outs.	The study is limited to a peripheral hospital in India, limiting nationwide and global generalisability.	Digital transition also presents challenges such as technology interruptions, a learning curve, and resistance from end users.
Rehman et al., 2022; International	IEEE Transactions on Computational Social Systems	3	Legitimacy and Technology	Online pharmacies give opportunities for counterfeit vaccines to enter authentic supply chain. Blockchain based framework to mitigate them.	Blockchain based data management framework with regulatory monitoring makes vaccine supply chains transparent, and security.	The framework limits customer feedback and cold chain monitoring aspects of the supply chain to ensure drug quality and integrity.	Global incorporation of these approaches restricts entry of counterfeit vaccines enter into the supply chain.
Sarkale et al., 2022; India	Journal of Pharmaceutical Negative Results	-	Legitimacy and Pricing	Attractive pricing on online pharmacies increases traction but questions authenticity.	Survey results show that refill reminders, door step delivery and convenience are among the top reasons for e-buying behaviour.	The survey was conducted in India with 244 participants, limiting the generalisability of these findings.	Delivery of wrong medicines and the authenticity of the drugs are the key challenges among online pharmacy customers.
Singh and Chaddah, 2021; India	Asia Pacific Journal of Health Management	5	Legitimacy Pricing and Technology	Blockchain builds trust to address customer's privacy concerns using online pharmacies.	Blockchain enabled supply chain with public-private partnerships increases efficiency transparency and acceptance.	The study and framework is designed to Indian context, limiting generalisability to global scenarios.	Survey results show that data privacy, secure transactions and drug counterfeits are major concerns.
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Wang et al., 2016; China	Drugs and Therapy Perspectives	-	Dual Channel Operations and Pricing	In China, drugs for cardiovascular disease are priced multiple times higher than the international reference price.	The availability of drugs in online pharmacies is 70 % for generic drugs while its 47 % for branded drugs; the pricing is 3.4x and 14.7x respectively.	The sample size of the study was small with only 17 drugs studied. The availability at the moment analysis and didn't account for fluctuations.	Online pharmacies observed not to offer competitive pricing for more expensive drugs; high profit margins. 'online-to-offline' strategy improves service quality.
Zhao, Muthupandi and Kumara, 2020; US	Journal of Medical Internet Research	12	Legitimacy and Technology	Tackling illicit online pharmacies is critical to maintaining the integrity of the drug supply chain.	Illicit online pharmacies can be tracked based on their web traffic activities.	The limited availability of online pharmacies' web traffic data challenges this model's reliability.	E-commerce markets and payment companies can implement these models to warn customers about illicit risks.

Data availability

Data will be made available on request.

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