Textile industry innovation: Systematic review of key trends and particularities

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ABSTRACT

Innovation in the textile industry is a key strategic factor, influenced by geographic disparities, structural challenges, and rapid technological change. However, fragmented knowledge makes it difficult to fully understand the phenomenon. This study aimed to analyze how various types of innovation appear and interact in the global textile sector. A systematic literature review was carried out following PRISMA 2020 guidelines, using Scopus and Web of Science databases. From an initial pool of 94 articles, 19 met the inclusion criteria. Findings reveal that beyond specific advancements like automation or smart textiles, structural tensions hinder the integrated adoption of technological, organizational, and sustainability innovations. The diversity of analytical approaches shows there is no single, unified path to innovation in this sector. Instead, multiple innovation trajectories coexist, influenced by local conditions and unequal institutional capacities. In addition, knowledge gaps between developed and emerging regions, as well as the lack of focus on early stages of the supply chain, highlight the need to rethink research priorities. Ultimately, innovation in the textile industry must be understood as a comprehensive process that brings together technology, organizational change, and sustainability, requiring a holistic approach to improve competitiveness and ensure long-term transformation across the sector.

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1. INTRODUCTION

The textile industry is a fundamental component of the global economy, providing employment to over 300 million individuals across its value chain and contributing approximately 2% of global gross domestic product (GDP). This encompasses sectors such as apparel, technical textiles, and fast fashion [1], [2]. The analysis indicates that China, India, and Bangladesh are predominant in terms of mass production, while the European Union and the United States are at the forefront of innovation based on high added value [3].

In this context, sustainability has emerged as a pivotal factor in determining competitiveness. The mounting pressure from conscientious consumers and increasingly stringent regulations has compelled companies to undertake the process of redesigning, incorporate green technologies, and adopt more efficient models. This strategic response aims to address the sector's escalating environmental challenges, including the intensive use of water, energy, and polluting materials, while concurrently maintaining their competitive position in an increasingly demanding global market [4].

Innovation in the textile industry is defined as the introduction of new or significantly improved processes, products, materials, and business models with the aim of increasing the sector's efficiency, sustainability, and competitiveness. In consideration of this approach, notable trends emerge, including the advancement of smart textiles, the automation of production processes, and the adoption of circular economic models aimed at reducing waste [5].

The textile industry has undergone a significant transformation in recent years due to digitalization, sustainability, and automation. The integration of technologies such as nanotechnology [6], artificial intelligence, 3D printing, and the Internet of Things (IoT) has enabled the optimization of processes and the creation of innovative products [7]. Consequently, the emergence of sustainable materials, including biodegradable textiles and recycled fabrics, has been driven by mounting environmental concerns and the imperative to mitigate the sector's ecological footprint. Innovation has been identified as a key factor in improving the current and future performance of the textile industry [4].

Nevertheless, there are notable lacunae in the articulation of knowledge regarding the various forms of innovation that are occurring within the sector. Despite advances in automation processes, smart textiles, and circular economy models, understanding of how these elements converge and integrate effectively remains limited [8]. This issue is further compounded by the fragmentation of knowledge in this area, which hinders the generation of holistic strategies that would allow companies to leverage the available innovative potential [3].

A significant challenge confronting the textile industry pertains to the complexity inherent in the integration of diverse innovation types, including product, process, organizational and marketing innovations, in a cohesive manner. The development of these innovations is frequently a decentralized process, lacking a unifying vision. This hinders the development of synergies between innovations, consequently creating obstacles to their large-scale implementation. For instance, a company may incorporate automated machinery (process innovation) without a flexible organizational model that facilitates its adoption or a commercial strategy that adequately communicates the value of the new product to the customer. This phenomenon serves to diminish the tangible impact of innovations on competitiveness, particularly within an environment where expeditious adaptation to market fluctuations is paramount for achieving success [9].

Notwithstanding the technological progress witnessed in the textile industry, research gaps persist with regard to the differences in innovation between leading and emerging markets. The extant literature does not delve into how these dynamics vary or what strategies can be adapted between contexts to strengthen the development of the sector [10]. This absence of clarity also curtails comprehension of the implementation of emerging technologies, including artificial intelligence, 3D printing, and the IoT. These technologies have exhibited their capacity to transform the production and customization of textiles. However, the adoption of these technologies remains constrained by economic, technological and training barriers. These challenges are further compounded by a paucity of studies that address these issues in a comprehensive manner, thereby hindering the sector's transition towards a more efficient and sustainable model [11].

Therefore, the scientific question that guides this research is: How are the different forms of innovation technological, organizational, and sustainable interrelated and manifested across the global textile industry, and what contextual factors explain their integration or fragmentation? This guiding question seeks to connect the fragmented insights found in the literature into a coherent understanding of how innovation operates as a multidimensional process within the sector.

In this regard, the objective of this research is to analyze how different types of innovation are manifested and articulated in the global textile industry, considering their characteristics, barriers, and opportunities in different geographic and economic contexts. The following research questions have been identified as the primary guides in this endeavor:

a. Which countries are leading in innovation in the textile industry, and what factors explain their position?
b. Which stages of the textile production chain have the highest levels of innovation?
c. What types of innovation are most widely implemented in the textile industry globally?
d. Which emerging technologies are transforming innovation in the textile sector?
e. What are the effects of textile innovation on the sustainability and competitiveness of the sector in the main markets?

This study provides a comprehensive view of innovation in the textile industry by combining technological, economic, and sustainability perspectives, enabling a multidimensional approach. The value of the study lies in its comparative analysis of leading and emerging markets, facilitating the identification of patterns and differences in the adoption of innovations. The proposal of a conceptual framework is also made, which is intended to provide a framework for guiding future research in the field, as well as offering tools for strategic decision-making in the sector. The latter aspect is of particular importance in promoting competitiveness and sustainable development.

2. METHODOLOGY

The research adopts the preferred reporting items for systematic reviews and meta-analyses (PRISMA 2020) methodology, an updated guide that seeks to improve the quality and transparency of systematic reviews through search criteria that structure the process of identifying, selecting, evaluating, and synthesizing scientific evidence. This methodology is pertinent for the analysis of complex phenomena, such as innovation in the textile industry, as it guarantees traceability, reproducibility, and clarity at each stage of the analysis. The application of this process is twofold: firstly, it serves to minimize bias, and secondly, it ensures the validity of the process as a whole. Furthermore, it facilitates the comparison of findings with those of other similar studies, thereby reinforcing the commitment to international standards of academic quality [12]. The methodology encompasses eligibility criteria, information sources, a search strategy, selection criteria, and data processing.

2.1. Eligibility criteria

The eligibility criteria for the documentation to be included were defined on the basis of three aspects: thematic, documentary and methodological. The aim of this was to ensure the quality and relevance of the studies.

a. Documentation aspects: The following publications were included in the review: original articles, systematic reviews and academic communications presented at peer-reviewed scientific conferences. The period of publication was restricted to 2023–2025, with the objective of guaranteeing the relevance of the contributions. The selection of documents was restricted to those in English and Spanish, with the objective of ensuring comprehension and analysis that was devoid of any potential distortion arising from the process of translation.
b. Thematic aspects: Thematic relevance was prioritized, with studies focusing on innovation in the textile, clothing, fashion, or apparel industries given particular consideration, especially those focused on emerging technologies.
c. Methodological aspects: The presence of theoretical frameworks or models that addressed innovation from technological, organizational, commercial, or process dimensions was assessed, following the categories of the 2005 Oslo Manual.

The exclusion process was conducted in three phases. The initial phase entailed the identification and elimination of indexing errors, the removal of duplicates, and the exclusion of records lacking complete metadata. The second group of studies was excluded from the analysis due to the unavailability of the full text, which was the result of either editorial restrictions or a lack of institutional availability. The third approach was based on thematic evaluation, whereby the abstract and, when necessary, the body of the text were reviewed to exclude works not directly related to the subject of study.

The implementation of this triple validation process enabled the minimization of bias, the assurance of the coherence of the selected corpus, and the enhancement of the traceability of the process. These elements are imperative for ensuring a systematic review that is rigorous, reproducible, and comparable, thereby establishing a robust foundation for future research.

2.2. Sources of information

For the purpose of collecting scientific literature, the Scopus and Web of Science databases were selected as the primary sources on the basis of their editorial quality, broad geographic scope, multidisciplinary thematic coverage, and rigorous indexing processes. These platforms are regarded as the gold standard in the field of systematic reviews due to their unwavering reliability and meticulous selection process, which ensures the inclusion of publications that have been validated by recognized organizations. Scopus, a bibliographic database managed by Elsevier, indexes peer-reviewed scientific literature in a range of fields, including engineering, technology, social sciences, economics, management, and design. This comprehensive coverage facilitates a multifaceted exploration of innovation within the textile industry. Web of Science, which is operated by Clarivate, integrates collections such as the science citation index and the social sciences citation index, thereby enabling access to relevant studies in innovation management, industrial sustainability, and technological processes applied to the textile sector. It is evident that both sources represent developed and emerging regions, albeit with disparities in thematic and regional coverage [13].

2.3. Search strategy

The search strategy was devised in accordance with the established inclusion criteria and adapted with precision to the structures inherent to each database. For the Scopus database, the following equation was utilized:

$$TITLE\ (textile\ OR\ clothing\ OR\ apparel\ OR\ fashion)\ AND\ (TITLE\ (Innovation\ AND\ technolog)\ OR\ AUTHKEY\ (Innovation\ AND\ technolog))\ AND\ PUBYEAR\ >\ 2022\ AND\ PUBYEAR\ <\ 2026\ **$$

$$For\ Web\ of\ Science, the\ equation\ was\ adapted\ according\ to\ its\ search\ syntax\ and\ was:$$

$$TI = (textile\ OR\ clothing\ OR\ apparel\ OR\ fashion)\ AND\ (TI = (Innovation\ AND\ technolog)\ OR\ AK = (Innovation\ AND\ technolog)), applying\ the\ time\ filter\ manually, rather\ than\ from\ the\ equation.$$

It is evident that both equations are characterized by the integration of Boolean operators (AND, OR), truncations (technology*), and field-specific delimiters. The time restriction to the period 2023–2025 aligns with the established documentary and thematic criteria. This formulation ensures the systematic and accurate retrieval of relevant studies for the analysis of innovation in the textile industry.

2.4. Selection process

The selection process was initiated with a total of 94 identified documents, of which 67 were from Scopus and 27 from Web of Science. The three exclusion phases previously outlined were then executed in succession. The procedure was carried out by a single reviewer who systematically applied the defined filters. Microsoft Excel was utilized to oversee and systematize the corpus, a tool that facilitated the management of the progress of each phase of the process. Figure 1 presents a flowchart that summarizes the stages developed and the results obtained in each.

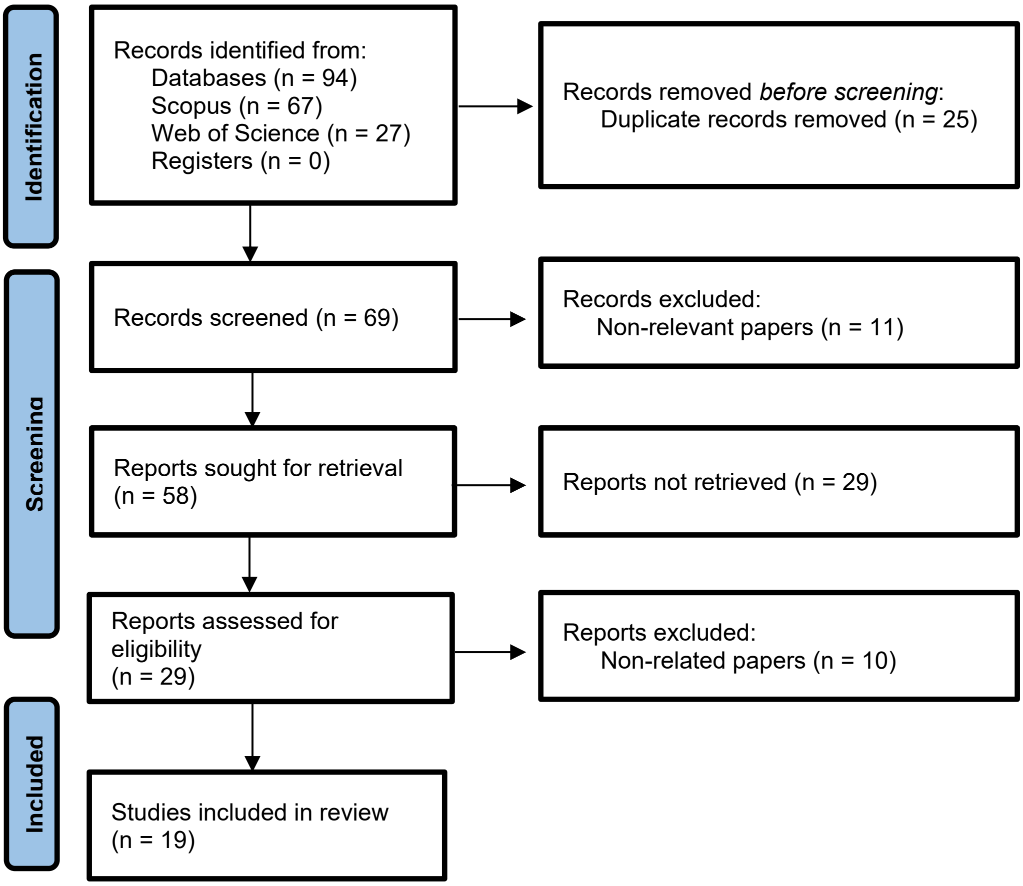

Figure 1. PRISMA flowchart based on Scopus and Web of Science

2.5. Data processing

Microsoft Excel was utilized for the purpose of data processing, with the objective of organizing and systematizing the information that had been extracted from the selected documents. The following variables were included: author, year of publication, country of origin, type of innovation analyzed, specific sector within the textile industry, key findings, applied theories, and methodology used. The data coding structure was designed to enable both qualitative and quantitative analysis, thus facilitating the identification of patterns, categories, and thematic relationships. A cross-validation process was applied through a systematic review of records to ensure the consistency of the collected data and to minimize transcription or interpretation errors.

2.6. Risk of bias

The potential for bias in the selection of studies was mitigated through the implementation of a rigorous review process at each stage of the search and filtration procedure. The principal sources of bias identified were the restriction of the languages used to English and Spanish, the potential exclusion of unpublished studies or studies with negative results, the limited timeframe of recent publications, and the reliance on two specific databases. The potential for bias was identified as arising from the terms employed in the search equations and the manner in which the studies documented their findings. In order to reduce these limitations, a set of standardized selection criteria were applied, double-checking was performed during the screening process, and the equations were validated based on the research objectives and the adopted conceptual framework.

3. RESULTS

The following section is dedicated to the presentation of the primary findings derived from the analysis of the selected documents. These findings have been organized according to the research questions that guided the study. Each subsection develops a specific thematic axis, thus facilitating comprehension of the contemporary dynamics of innovation in the textile industry. The study addresses aspects such as the countries with the greatest leadership in innovation, the stages of the production chain experiencing the greatest transformations, the most recurrent types of innovation, emerging technologies shaping new practices, and the effects these innovations generate on the sustainability and competitiveness of the sector. The present approach is intended to provide a systematic and comparative interpretation of the main trends, key players, and results observed in the analyzed markets. Table 1 provides a synopsis of the studies that were incorporated into the analysis process.

Table 1. Studies included in the research based on Scopus and Web of Science

Title	Authors
Analysis of patent innovation evolution and layout characteristics of global new textile materials technologies	[14]
Changes in technological innovation efficiency and influencing factors of listed textile and apparel companies research--Based on three-stage DEA with Tobit modeling	[15]
Do not stop the loop: Driving circular textiles with technology and stakeholder engagement	[16]
Innovation of anti-viral, anti-bacterial and water-repellent textile wall hanging, depending on nanotechnology and modern printing technologies	[17]
Innovative application and design of smocking technology in local Chinese clothing brands	[18]
Investments in digital technology advances in textiles	[19]
Leveraging 4D golf apparel wear simulation in online shopping: A promising approach to minimizing the carbon footprint	[20]
Revolutionizing the runway: how technological and marketing innovation fuse market sensing on marketing performance in fashion industry	[21]
Technological and non-technological trends in fashion eco-innovations	[22]
The influence mechanism of digital technology empowering green innovation of textile firms: a knowledge search perspective	[23]
An authentic human-like figure: the success keys of AI fashion influencer	[24]
Assessing the barriers of integrating technological innovations in textiles sector: Implications towards sustainable production	[25]
Consumer values, online purchase behaviour and the fashion industry: an emerging market context	[26]
Examining the effectiveness of the South African apparel industry’s systems of innovation	[27]
Firm-level technological upgrading process in low-tech industries: The case of clothing industry in Brazil	[28]
Innovation of clothing design element extraction and CAD system based on computer vision and multimedia analysis technology	[29]
Propensity for innovation in textile manufacturing companies at the city of Gaspar/SC, national capital of children’s fashion	[30]
Responsible innovation and ethical corporate behavior in the Asian fashion industry: A systematic literature review and avenues ahead	[31]
Value co-creation by interactive AI in fashion E-commerce	[32]

As illustrated in Figure 2, the distribution of the studies analyzed by country is presented. China is the most represented country, with five studies, followed by Brazil with three. Several other countries have two studies, including Bangladesh, the United States, India, Indonesia, and Italy. A number of other countries are represented by a single study each, including Germany, South Korea, Egypt, France, Japan, Malaysia, Nigeria, and Serbia. This geographic diversity is indicative of extensive participation, from both emerging and developed economies, in the study of innovation in the textile industry.

A comprehensive review of seven distinct stages within the textile production chain was conducted, encompassing the extraction of fibers, the process of spinning, weaving, the design stage, garment manufacturing, the manufacturing of other products, and the treatment of fabrics. The results indicate a preponderance of studies centered on advanced stages of the textile production chain, including garment manufacturing and design. The most frequently referenced area was garment manufacturing, with 18 mentions, followed by design (16), fabrics (10), yarns (6), and fiber production (5). Stages such as the manufacturing of other products (2) and fabric processing (1) appear with less frequency. This distribution enables the observation of which phases of the chain focus research on innovation in the textile sector, as demonstrated in Figure 3.

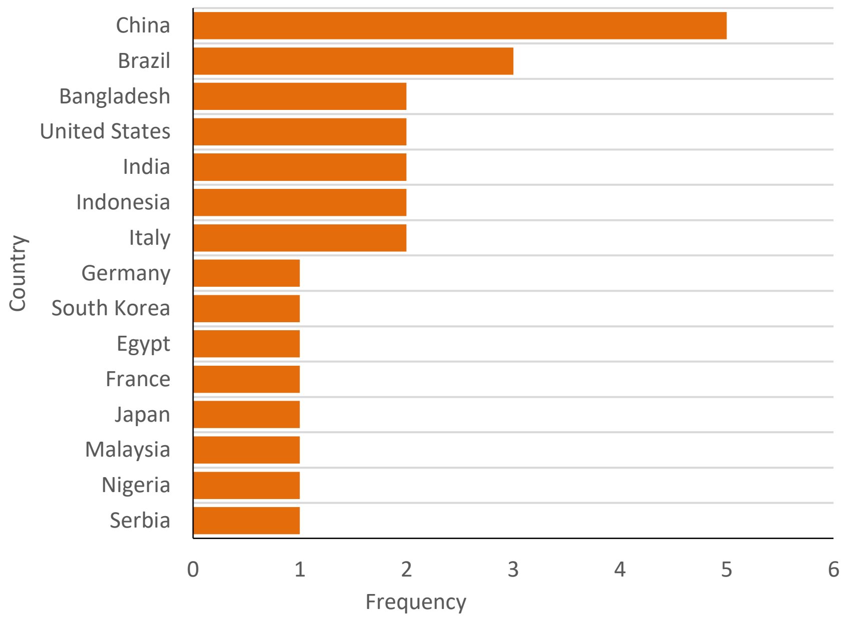

Figure 2. Country of study in textile innovation based on Scopus and Web of Science

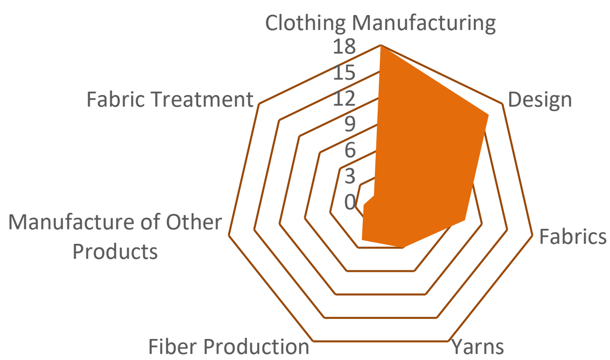

Figure 3. Stages of the textile production chain based on Scopus and Web of Science

The literature review identified various approaches to the innovation applied in the textile industry, using the classification proposed in the 2005 version of the Oslo Manual as a point of reference. This document, prepared by the Organization for Economic Co-operation and Development (OECD) and Eurostat [33], defines four main types of innovation: namely, product, process, organizational and marketing innovation. In accordance with this typology, product innovation was identified as the most frequently referenced, with a total of 17 studies, followed by organizational innovation (15), business process innovation (13), and marketing innovation (9). This distribution is indicative of a variety of approaches to innovation, demonstrating that transformations in the sector are not limited to a single type but encompass multiple dimensions of business activity, as demonstrated in Figure 4.

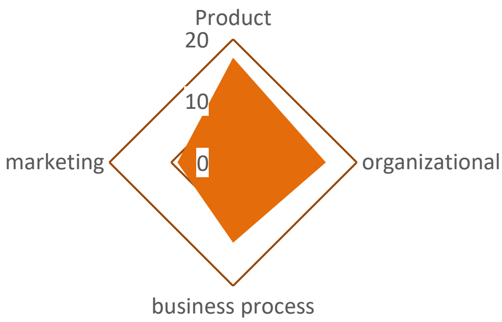

Figure 4. Types of innovation in the textile sector based on Scopus and Web of Science

To provide a structured overview of automation and robotics applications identified in the reviewed studies, Table 2 presents a taxonomy of technologies according to the type of process or operational function within the textile value chain. This classification highlights how automation has permeated both core manufacturing tasks and supporting systems, revealing varying levels of technological maturity and diffusion across regions.

Table 2. Taxonomy of robotics and automation applications in the textile industry

Process/Function	Automation/Robotics Technology	Main Applications	Reported Benefits	Representative Studies
Fabric cutting and handling	Robotic arms, CNC cutting systems, laser-guided platforms	Automated material loading, precision fabric cutting, transfer between stages	Reduced material waste; higher precision and speed	[19], [25], [28]
Weaving and knitting	Programmable looms, robotic yarn feeders, tension sensors	Real-time control of weaving patterns, yarn management	Increased efficiency; improved consistency of textile structures	[19], [23]
Sewing and garment assembly	Collaborative robots (cobots), machine vision systems	Automated stitching, seam alignment, and adaptive assembly	Enhanced productivity; lower defect rates	[21], [24], [25]
Inspection and quality control	Computer vision, AI-based defect detection, smart cameras	Real-time fabric inspection and classification	Error reduction; continuous monitoring of quality	[19], [23]
Logistics and material transport	Automated Guided Vehicles (AGVs), autonomous conveyors	Internal transport between production zones	Optimized workflow; reduced manual labor	[19], [25]
Maintenance and process monitoring	IoT sensors, predictive analytics, robotic maintenance units	Equipment status monitoring, predictive maintenance	Reduced downtime; extended equipment lifespan	[23], [34]

3.1. Automation and robotics in textile manufacturing

The analysis of the reviewed literature reveals that automation and robotics are among the most transformative forces driving innovation in textile manufacturing. Several studies report the implementation of robotic arms for tasks such as fabric handling, cutting, and sewing, significantly improving accuracy and reducing production time [19], [25]. Automated guided vehicles (AGVs) and robotic inspection systems have also been adopted to streamline logistics and quality control processes. Moreover, the integration of computer vision and machine learning has enabled intelligent defect detection and adaptive production lines, reducing material waste and human error. In emerging economies, however, the adoption of robotics remains limited due to high investment costs and the scarcity of specialized technical labor. Figure 5 illustrates these technologies as core enablers within the broader landscape of textile innovation.

A range of emerging technologies associated with innovation in the textile industry were identified among the studies analyzed. The field of artificial intelligence is at the forefront, with 20 mentions, followed by digital platforms (14), smart textiles, and automated machinery (8 each). It is also noteworthy that technologies such as the Internet of Things, nanotechnology, computer-aided design, and eco-sustainable technologies have a minor yet significant presence. Finally, the paper reports on advances such as 4D garment simulation and the use of functional fibers. The results of this study are presented in Figure 5.

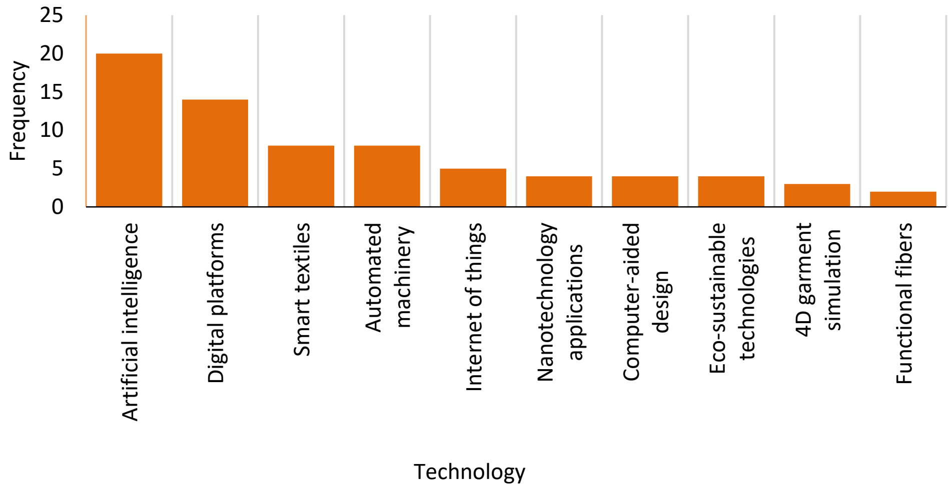

Figure 5. Emerging technologies in the textile industry based on Scopus and Web of Science

The results obtained demonstrate a variety of impacts generated by innovation in the textile industry, with a strong presence of aspects related to sustainability and competitiveness in the publications for the 2023-2025 period. Operational efficiency was the most frequently mentioned area of concern (13 mentions), followed by stakeholder relations (12) and environmental sustainability (10). Additionally, the text emphasizes dimensions such as human capital, digital transformation, innovation quality, impact reduction, and other pivotal factors that fortify the sector's strategic positioning. The findings are summarized in Figure 6.

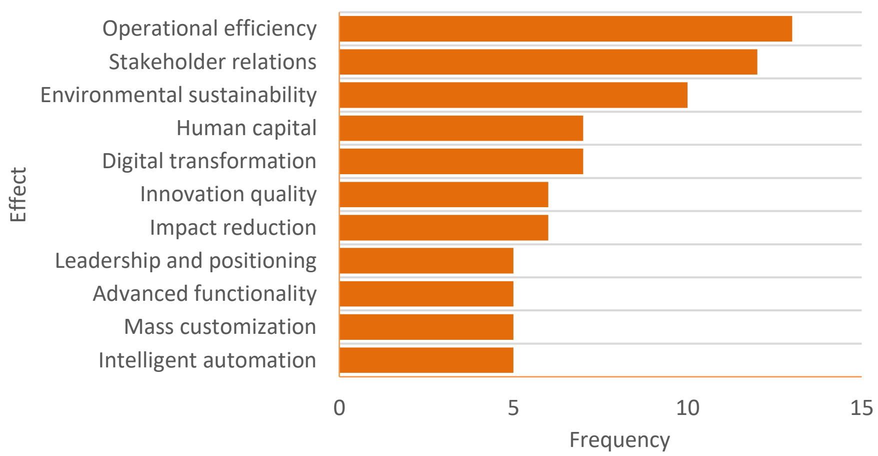

Figure 6. Impacts of textile innovation. Prepared by the authors based on Scopus and Web of Science

The results of the systematic review were organized according to the research questions posed, allowing for the identification of key patterns in innovation within the textile industry. This structuring facilitated the analysis of variables related to the geographical context, the stages of the production chain, the types of innovation applied, and the emerging technologies involved. This classification facilitated the identification of general trends in the academic approach to the topic, as well as a diversity of approaches that reflected the complexity of the innovation phenomenon in this productive sector. The presentation of these findings is structured and comparative, with each figure offering a distinct perspective.

4. DISCUSSION

This section provides an interpretative analysis of the main findings, contrasting them with the existing literature to clarify how innovation operates in the textile industry. Rather than introducing new data, it focuses on synthesizing relationships between technological, organizational, and sustainability dimensions, while situating them within the broader context of Industry 4.0 transformation.

4.1. Analysis of results

The review confirms that China leads research and patent production in textile innovation, reflecting its industrial policy orientation toward technological upgrading and efficiency. However, as Wang *et al.* [14] and Chen and Chen [15] indicate, this leadership is still accompanied by challenges in innovation quality and diffusion. This pattern contrasts with countries such as the United States, Japan, and Italy, where innovation tends to be more collaborative and sustainability-oriented.

Across the reviewed studies, innovation manifests through four interconnected dimensions product, process, organizational, and marketing innovation—each reinforcing different aspects of competitiveness [22], [26]. This interrelation reveals that innovation in the textile sector functions as a multidimensional system rather than a linear process. For instance, organizational innovations support the adoption of automation technologies, while marketing strategies amplify the social acceptance of sustainable fashion. Such interdependencies explain why isolated innovations rarely achieve large-scale transformation.

Additionally, the predominance of research on advanced stages of the production chain design and manufacturing—demonstrates the current imbalance in innovation focus. As Di Vaio *et al.* [31] suggest, this orientation reflects market proximity and consumer-driven sustainability demands. In contrast, Alam *et al.* [25] and Piana and Brustolin [28] highlight persistent structural barriers in early stages such as fiber or yarn production, where limited investment and technological capability restrict comprehensive innovation.

Digital transformation emerges as a unifying trend, expressed through artificial intelligence, industrial automation, and digital platforms [19]. These technologies act as catalysts for process efficiency, personalization, and sustainable resource management. However, their adoption remains uneven due to disparities in infrastructure and human capital. This asymmetry reinforces the need to view innovation as an ecosystemic process shaped by economic and institutional context rather than solely technological progress.

4.2. Comparison of results with other studies

The patterns identified in this review align with those reported by Dantas [34] and Monteiro *et al.* [35], who emphasize the role of Industry 4.0 technologies—such as the IoT, additive manufacturing, and data analytics—in transforming production systems. Both works converge with the present findings in showing that digital maturity and organizational culture are decisive for innovation success.

Similarly, the sustainability dimension observed in the reviewed studies resonates with Todeschini *et al.* [36] and Hora *et al.* [37], who demonstrate that circular economy models and sustainable business practices are still in early adoption phases. The current review reinforces this view, showing that while sustainability is increasingly integrated into discourse, its practical implementation remains fragmented.

In contrast, Dasgupta *et al.* [38] provide a more technical perspective focused on environmental management, particularly wastewater treatment innovations. When compared with that approach, this review contributes a holistic understanding of innovation by connecting environmental solutions with organizational and technological strategies across the entire value chain.

Overall, the discussion reveals that innovation in the textile industry is shaped by a combination of enabling technologies, institutional capabilities, and sustainability imperatives. These interactions explain regional disparities in innovation outcomes and highlight the importance of coordinated strategies that integrate technological advancement with organizational and environmental objectives.

To strengthen the historical perspective of automation and robotics in the textile industry, the review period was extended to include studies published between 2000 and 2015. These earlier works provide valuable insights into the technological evolution that preceded the current Industry 4.0 paradigm. They address topics such as nanotechnology applications, innovation-driven R&D, cross-industry knowledge transfer, regional innovation systems, and early forms of textile automation. Specifically, Shishoo [39], [40] and Holme [41] explored the foundations of innovation-driven research and high-performance textiles, while Kaounides *et al.* [42] highlighted the emergence of nanotechnology as a precursor to intelligent manufacturing. Similarly, Enkel and Gassmann [43] proposed a framework for cross-industry innovation that influenced later automation practices, and Kuştepeli *et al.* [44] together with Molina-Morales and Expósito-Langa [45] demonstrated how regional networks and cluster dynamics facilitated technological adoption. The inclusion of these studies reinforces the longitudinal depth of the analysis and contextualizes the progressive integration of robotics and automation across different eras of textile innovation. See Table 3.

Table 3. Structured analysis of studies (2000–2015) on textile robotics, automation, and innovation

Ref.	Focus of study	Type of Innovation/Technology	Main contributions	Relevance for automation
[39]	Innovation-driven R&D in textile manufacturing	Organizational and technological innovation	Identifies R&D as the central driver of long-term textile competitiveness	Establishes the conceptual foundation for linking automation and R&D strategies
[40]	Global challenges and innovation trends	Technological and process innovation	Analyses structural changes shaping modern textile markets	Highlights early automation and mechanization trends
[42]	Nanotechnology diffusion in textiles	Technological innovation	Examines early integration of nanotech into textile processes and markets	Shows how automation supported precision finishing and smart materials
[41]	Technological innovation in textile finishing	Product and process innovation	Reviews new chemical and mechanical finishing techniques for high-performance fabrics	Describes semi-automated finishing systems as precursors to smart manufacturing
[43]	Cross-industry innovation models	Organizational innovation	Introduces cross-sectoral knowledge transfer as a source of innovation	Provides framework for adapting automation solutions from other industries to textiles
[44]	Regional innovation systems and clusters	Organizational and process innovation	Analyses regional disparities and network effects on innovation performance	Indicates how cluster connectivity accelerates automation diffusion
[45]	Cluster networks and innovation efficiency	Organizational innovation	Demonstrates that inter-firm collaboration amplifies innovation results	Suggests that automation adoption is enhanced by inter-organizational cooperation

4.3. Proposed conceptual framework

Figure 7 presents a conceptual framework that synthesizes the key relationships identified in the review of innovation in the textile industry. The model's focal point is the categories of innovation delineated by the 2005 Oslo Manual (namely, product, process, organizational, and marketing innovations). These categories are intricately interwoven with emergent technologies, such as artificial intelligence, automation, and the IoT, which function as pervasive enablers. These relationships are linked to the stages of the production chain, predominantly in design and manufacturing, and the reported impacts on sustainability and competitiveness. Furthermore, regional particularities are taken into consideration, which serve to moderate the focus and maturity of the implemented innovations.

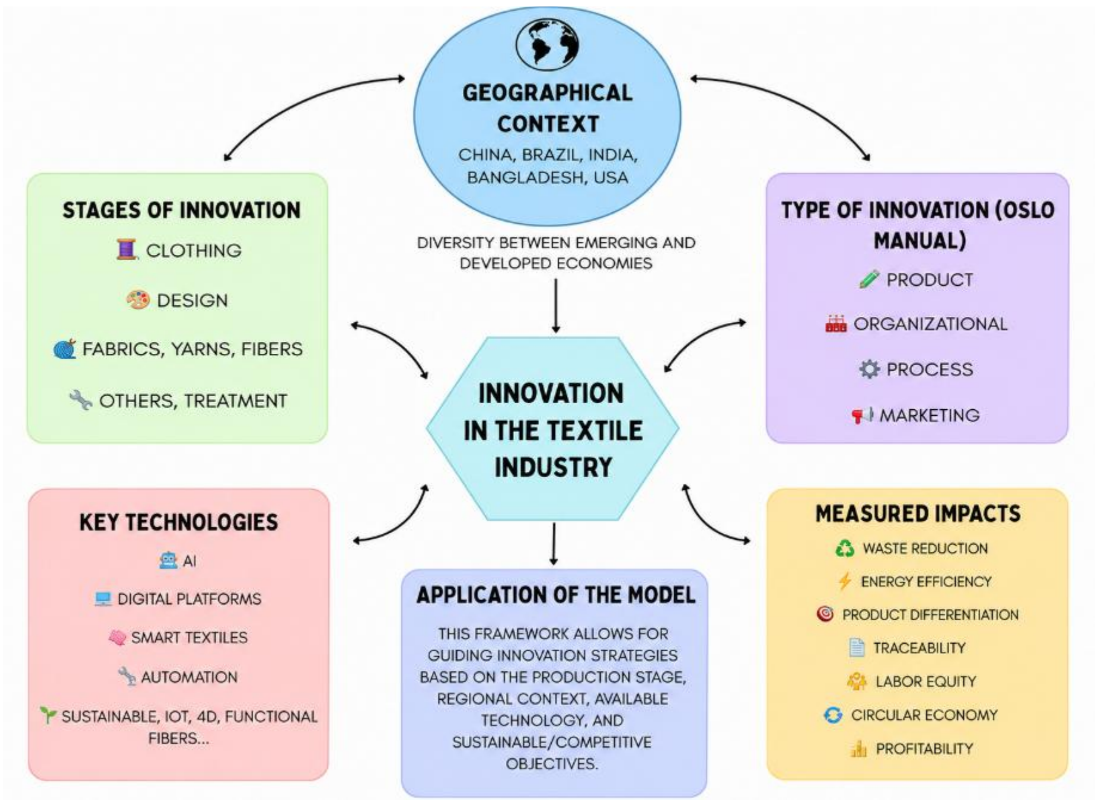

Figure 7. Conceptual framework on textile innovation (Prepared by the authors)

4.4. Implications

The results obtained in this systematic review of innovation in the textile industry offer important implications on three interrelated levels: theoretical, political, and practical. The following discussion will address these implications in the context of the empirical evidence collected and the categories analyzed.

4.5. Theoretical implications

From a theoretical standpoint, the findings contribute to an expanded comprehension of sectoral innovation by demonstrating that the textile industry, in its conventional conception, is not confined to product innovation but rather exhibits a multifaceted interaction between process, organizational, and marketing innovations. This multidimensional approach contributes to the enrichment of the body of knowledge on innovation models applied to mature sectors, such as textiles. It also allows us to transcend traditional frameworks that are focused solely on the development of new goods.

Furthermore, the results reveal the growing importance of emerging technologies as cross-cutting enablers at different stages of the production chain, providing elements for the evolution of conceptual frameworks such as the technology-organization-environment framework (TOE) or the diffusion of innovations (DOI) theory in industrial contexts. The emphasis on technologies such as artificial intelligence, digital platforms and automated machinery underscores the interrelation between technology and the organizational environment, which is instrumental in propelling innovation within the textile industry. Moreover, the ramifications for sustainability and competitiveness emphasize the necessity to incorporate digital maturity, the institutional environment, and cluster logic into the models. This integration broadens the TOE perspective by encompassing factors associated with digital transformation and industrial ecosystems.

Moreover, an analysis of geographical disparities in innovation strategies, with notable contributions from countries such as China, Brazil, India, and Italy, facilitates the development of scholars in the field. This advancement enables the establishment of comparative frameworks that consider local dynamics, developmental levels, and the orientation of industrial policies. In this sense, the results of the study suggest the construction of more situated contextual frameworks that recognize the heterogeneity of innovation trajectories according to the national and regional environment.

4.6. Political implications

At the public policy level, the results obtained allow for the identification of key gaps and opportunities to strengthen innovation in the textile sector. The majority of studies concentrate on the advanced stages of the chain, such as garment manufacturing and design. This suggests a need for greater incentives and programs to foster innovation in the early stages, such as fiber, yarn and fabric production, which have traditionally lagged behind in technological terms.

For industrial policymakers, this implies the need to design differentiated instruments that support the comprehensive technological development of the chain, especially in developing countries. The integration of emerging technologies, including artificial intelligence, nanotechnology, and eco-sustainable solutions, necessitates the implementation of financing mechanisms, technology transfer processes, and specialized training in digital competencies. These measures are crucial for expediting the transformation of the sector.

From the perspective of productive clusters and innovation agencies, the findings reaffirm the importance of fostering synergies between companies, universities, research centers, and technology developers. The promotion of collaborative spaces and the establishment of open innovation platforms have the potential to facilitate the adoption of solutions that are adapted to local realities. In addition, the promotion of policies that priorities sustainability and circularity is recommended, given that a significant proportion of the impacts documented in the analyzed studies pertain to energy efficiency, waste reduction and traceability. These elements are recognized as being pivotal in achieving the Sustainable Development Goals (SDGs).

4.7. Practical implications

In practical terms, the findings of this research are of particular relevance to textile companies, startups in the fashion-technology sector, universities, and research centers. For well-established companies, the results of this study allow them to identify opportunities for diversification in the types of innovation they can implement. Beyond the realm of product innovation, organizations are at liberty to explore improvements in their production processes, business models, or marketing strategies, a prospect facilitated by the existence of emerging technologies that have already been successfully implemented in other contexts.

The proposed framework assists startups and technology developers in comprehending which technologies are most pertinent to the textile ecosystem. This understanding can inform investment decisions, prototyping, and the development of digital solutions. The increasing use of digital platforms, smart textiles, and automated machinery, for instance, has given rise to new business models based on personalization, operational efficiency, and real-time traceability.

Specifically, for the field of textile automation, the findings highlight the strategic importance of integrating Industry 4.0 technologies—such as artificial intelligence, robotics, and data-driven systems—into production processes. These results demonstrate that automation not only enhances productivity and precision but also facilitates sustainable manufacturing by reducing waste and energy consumption. Scientifically, the study contributes to consolidating the understanding of automation as a multidimensional enabler of innovation, linking technological advances with organizational transformation and environmental performance. For the industrial community, this implies that investing in smart automation should be accompanied by policies that foster workforce training, digital infrastructure, and collaborative ecosystems among academia, industry, and government.

The reviewed evidence also demonstrates that robotics and automation represent the operational backbone of modern textile manufacturing. Their relevance extends beyond productivity improvements, as they support data-driven decision-making and adaptive control systems that align with the principles of smart manufacturing. The integration of robotic systems in spinning, weaving, and garment assembly processes illustrates a paradigm shift from manual labor to cyber-physical production environments. This transition demands new competencies in programming, system maintenance, and human–machine collaboration, reinforcing the need for interdisciplinary training programs. Consequently, the textile sector’s future competitiveness depends on how effectively it incorporates automation as a synergistic element within broader innovation and sustainability strategies.

Within the academic domain, the outcomes of such studies serve to direct future research initiatives towards the identification of thematic gaps. These thematic gaps may pertain to areas such as innovation in sustainable fibers, automation in primary production, or the adoption of blockchain technology for the purpose of traceability. Furthermore, they have the capacity to inspire the development of contemporary curricula in industrial design, textile engineering and fashion management programs, with the technological and sustainable dimensions serving as integral components of the educational framework.

4.8. Technical challenges and engineering perspectives

Despite the evident advances in automation, textile manufacturing faces unique engineering challenges due to the intrinsic deformability, flexibility, and heterogeneity of materials. Handling fabrics and yarns with precision is considerably more complex than manipulating rigid components, as deformable materials require adaptive gripping, variable tension control, and dynamic motion planning. Current robotic systems still struggle with these requirements, particularly in tasks such as fabric folding, seam alignment, and quality inspection where elasticity and friction vary continuously.

From an engineering standpoint, progress in soft robotics and machine vision has begun to address these limitations. Soft robotic grippers enable gentle yet firm manipulation of flexible materials, while computer vision combined with depth sensors improves real-time tracking of fabric deformation. However, scalability and cost efficiency remain barriers to industrial deployment. The integration of artificial intelligence (AI) and Internet of Things (IoT) systems represents the next step toward fully adaptive textile production environments. AI algorithms can predict deformation patterns, optimize sewing trajectories, and detect micro-defects through deep learning, whereas IoT-based sensor networks provide continuous feedback for energy use, machine condition, and material behavior.

The convergence of these technologies defines the architecture of smart textile factories, where autonomous machines communicate and self-adjust according to environmental and operational data. Yet, implementing such systems requires robust data infrastructure, cybersecurity measures, and workforce retraining in robotics programming, data analytics, and process integration. In this sense, the future of automation in textiles depends not only on technological breakthroughs but also on the capacity to harmonize mechanical engineering, computer science, and materials technology into an integrated ecosystem.

4.9. Limitations

This study, based on a systematic literature review, presents limitations inherent to its methodological approach that must be acknowledged for an adequate interpretation of the results. Firstly, there is a potential publication bias, given that the review focused on indexed academic articles, which may exclude technical studies, consulting reports, or innovations not formally documented. Moreover, the constraints imposed by the language criteria resulted in the exclusion of publications in languages other than English and Spanish, thereby potentially excluding relevant research conducted in languages such as Chinese, German, or French, which could offer alternative perspectives.

A further significant restriction pertains to the databases utilized, which, while selected for their scientific pertinence, may have resulted in the exclusion of relevant literature from local or specialized sources. The temporal limitations have also been recognized, as studies published within a specified timeframe were considered, which could have resulted in the exclusion of emerging innovations or those still undergoing validation. Finally, although global and regional patterns were identified, it is important to note that the findings cannot be generalized to all textile sector realities. This is due to the wide differences in technological capabilities, production structures, and socioeconomic contexts across regions and subsectors. Consequently, it is imperative to exercise caution when extrapolating the results.

4.10. Lines of future research

It is evident that, in view of the findings and the methodological limitations that have been identified, there are a number of opportunities to advance the study of innovation in the textile industry. Firstly, the development of in-depth case studies within companies of varying sizes and levels of digital maturity is recommended, with a particular focus on underrepresented regions or countries, such as Africa, Central America and Southeast Asia. This approach would facilitate a contextualized understanding of how innovation is adopted and implemented under specific conditions, thus providing a more comprehensive insight than that documented in the prevailing academic literature.

Consequently, there is an opportunity to promote interregional comparative research that analyses the differences and similarities in textile innovation dynamics between developed and emerging economies. This type of study could incorporate mixed methodological approaches, integrating qualitative analysis (interviews, observation, documentary analysis) with quantitative tools (surveys, network analysis, data mining) to capture both visible practices and the cultural, institutional, or informal factors that influence innovation processes.

It is also relevant to explore other segments of the textile chain that have been little addressed, such as the production of non-apparel products or the treatment and recycling of textile materials. These niche areas have the potential to reveal innovative dynamics aimed at sustainability, the circular economy, or waste reduction, which are not yet sufficiently documented. Furthermore, it is suggested that the spectrum of emerging technologies analyzed be expanded, including recent advances in biomaterials, quantum computing applied to design, advanced additive manufacturing, and cyber-physical systems applied to quality control.

Conversely, future research could concentrate on the analysis of the national and international regulatory frameworks that either facilitate or hinder innovation in the textile sector, with particular reference to environmental standards, traceability certifications, and labor regulations. This approach would facilitate the identification of discrepancies between public policies and actual technological capabilities, as well as the proposal of regulatory adjustments that promote sustainable competitiveness.

Finally, it is imperative to cultivate collaborative research endeavors between academic institutions, textile enterprises, innovation clusters, and technology centers, with the objective of generating technology transfer models that are tailored to local contexts. The potential for this research lies in its ability to contribute to the field by focusing on the design of sector-specific innovation indicators or by measuring the real impact of implemented technologies. A comprehensive perspective that incorporates environmental sustainability, social equity, and economic profitability is recommended.

5. CONCLUSION

Drawing upon the findings presented, this research facilitates a reflection on the profound heterogeneity that characterizes innovation in the textile industry. Firstly, the geographical breadth of the studies analyzed demonstrates global interest in the topic, as well as suggesting that innovation processes respond to specific local dynamics. These dynamics are influenced by each country's level of development, industrial capabilities, and public policies.

In response to the central scientific question, the review reveals that innovation in the textile industry functions as an interconnected system where technological, organizational, and sustainability dimensions converge unevenly across regions and stages of the value chain. The study demonstrates that this integration is stronger in countries with higher institutional capacities and digital maturity, while fragmentation persists in emerging economies due to limited access to technology, training, and coordinated strategies. This finding underscores that achieving holistic innovation in the textile sector requires synchronizing technological adoption with organizational transformation and sustainability objectives.

Secondly, the current focus of research on the final stages of the production chain necessitates a re-evaluation of the prevailing incentive structure. This structure tends to favor visible processes such as manufacturing and design, thereby neglecting critical phases for sustainability and technological advancement. Moreover, the coexistence of different types of innovation suggests that the sector is undergoing a transition towards more comprehensive models, where transformations respond not only to the logic of the product but also to organizational structures, operational flows, and market strategies.

Finally, the diversity of emerging technologies associated with these innovations poses challenges for the training of human talent and the adaptation of infrastructure. It is important to acknowledge that innovation in the field of textiles demands more than the mere application of technological advancements; it necessitates a comprehensive re-evaluation of the existing production model.

The conclusions are supported by evidence drawn from nineteen peer-reviewed studies published between 2023 and 2025 and retrieved from the Scopus and Web of Science databases. These studies encompass diverse methodological approaches, including quantitative analyses of innovation efficiency, qualitative assessments of sustainability practices, and case studies on technological adoption in both developed and emerging economies. The consistency of their findings regarding the interaction between digital transformation, organizational change, and sustainability provides a robust empirical basis for the integrative interpretation proposed in this review. The use of the PRISMA 2020 framework ensured methodological transparency and strengthened the reliability of the evidence underpinning the study's conclusions.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
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CONFLICT OF INTEREST STATEMENT

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.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author (A.A-C).

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