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Technological Convergence: The Analysis of Emergent Topics on Chitosan

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Abstract: This research identifies emergent topical trends of chitosan technology and its applications and constructs technological directions for business strategy in a hyper-competitive environment. A total of 2,612 scientific papers on chitosan technology published between 2010 and 2019 was retrieved from Web of Science (WoS) using various search queries. Results from bibliometric predictive intelligence (BPI) modelling highlight four major emergent topics related to technology convergence, namely shelf life, regenerative medicine, therapeutic agents, and antioxidant capacities. Four potential industries for chitosan application were identified: healthcare; cosmetics; agriculture; and food and beverages. The findings reveal a 75% increase in research publications since 2016 compared with previous years, which in turn illustrates the potential of technological goals to stimulate socially responsible research in the future.

Keywords: Technological Convergence (TC); Emergent topics (ETopics); Scientific Papers; Biopolymers; Bio-materials; Chitosan technology; Chitosan; Shelf life; Regenerative medicine; Therapeutic agent; Antioxidant capacity

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1 Introduction

Innovation is critical for attracting and retaining customers and market share in an increasingly competitive globalized business environment. To achieve product differentiation and cost leadership (Tanwar, 2013), monitoring technological convergence, which refers to the integration of disparate functions into a single system, is an effective tool to forecast the next generation of emerging technologies. Gleaning market patterns based on the directions of multi-technological research helps to agglomerate fuzzy database output to provide useful information for strategizing the direction of technology development resulting in cutting-edge products.

The application of technological convergence to forecast upcoming innovations is increasingly a hot topic in academia and industry. The emergence of growth engine industries using technological convergence to gain competitive advantage has generated a new agenda for industries, researchers, and governments in the search for developmental tools.

The innovation of new technologies and products through technology convergence has emerged as a world-wide trend due to the limitations of traditional 'stove pipe' technology. For example, bio-informatics convergence from information technology and bio-technology is an emerging area of genetic information technology that applies storage and analytical capabilities from information technology to biology. The goal of acquiring a competitive advantage in this field has stimulated fierce competition among the world's developed economies (Kang and Oh, 2012).

New and emerging technologies frequently appear at the intersections of various fields in the converging environment. Martin (1995) introduced the notion of the 'convergence of technological fields' among emerging technologies and highlighted some promising research areas for developing highly sustainable technologies that can yield long-term social as well as economic benefits. Such technologies have the potential to open up entirely new areas of science and industry (Breitzman and Thomas, 2015).

Polymers are found in every material used in our daily lives, including building and construction, packaging, consumer goods, electronics, and telecommunications. The economic growth of developing countries is a major factor contributing toward the growth of the polymer market, and this material's importance has been highlighted due to its applications in different dominions of science, technology, and industry. In recent years, synthetic polymers have begun to be supplanted by bio-polymers, which are safer for humans and more environmentally sustainable. For example, the bio-polymer called chitosan has varied applications in the medical, pharmaceutical, healthcare, cosmetic, and agricultural industries as well as food and beverages. The raw material for chitosan synthesis is waste from the fishery industry, specifically shrimp and other crustacean shells. Thus, chitosan synthesis transforms bio-waste into a value-added product that not only benefits the environment but also strengthens economic growth.

The objective of this research is to identify emergent topics related to chitosan technology and its applications in order to understand current trends and predict upcoming innovations and future technological directions for strategizing in a competitive market.

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2 Literature review

2.1 Technology convergence

The notion of industry convergence stems from the work of Rosenberg (1963), who described technology convergence as the application of similar skills, techniques, and facilities at the 'higher' stages of production to generate a vast range of products and services. Analysts expect that the increasing overlap among technologies, services, and firms will engender the merging of a growing number of industries and markets. This concept has become a strong focus of technological development research Hacklin, 2007; Stieglitz, 2003).

The term 'technology convergence' refers to a dynamic process in which varying industrial sectors come 'to share a common knowledge and technological base' (Athreye and Keeble, 2000, p.228). Although technology convergence has been widely accepted in practice, the concept of 'convergence' is rarely defined (Lind, 2005). Choi and Valikangas (2001) provided a general description of this term that refers to the blurring of boundaries between at least two previously discrete areas of science, technology, markets, and/or industries. Accordingly, technology convergence forecasts emerging fields of convergence to identify opportunities for future innovation (Geum et al., 2012). Publication and patent data have increasingly been utilized to measure technology convergence (Curran and Leker, 2011, Fai and von Tunzelmann, 2001). For example, Wang et al., (2019) created an innovative approach to identify emergent technology convergence areas and targeted patent information in a case study of 3D printing (Figure 1).

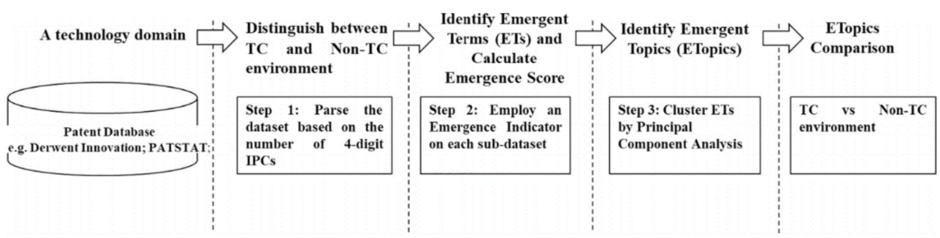

Figure 1 Overall process to generate emergent terms in relation to technological convergence. (Wang et al.,2019)

2.2 Emergent technologies

Forecasting emerging technologies is full of challenges. Prediction has been demonstrated to be an effective tool for anticipating and understanding the potential patterns, pace, and impacts of technological change (Porter and Roper, 1991); however, it

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is more difficult to forecast the emergence of new technologies. Like, 'convergence', the concept of emergence is 'widely used but seldom defined' (Cozzens et al., 2010), perhaps because the term is used in diverse ways (de Haan, 2006). Goldstein (1999) characterised emergence as comprising radical novelty, coherence or correlation, dynamical, and perceivable. The properties most commonly associated with emergence across all definitions are novelty and growth.

Cozzens et al. (2010) classified emergent technology forecasting methods into two main categories: (1) searching for rapidly increasing publications in an existing field or topic; and (2) data mining, which entails identifying patterns of emergence through co-occurrence analysis of keywords (co-keywords) and citations (co-citations). Bibliometric analysis is a quantitative data mining method that complements expert assessments of scientific and technological emergence (Boyack et al., 2014, Huang et al., 2015). Two main directions predominate bibliometric data mining: 1) identifying existing emergent technologies (Cho and Shih, 2011); and 2) predictive analysis that recognizes new technologies prior to their actual emergence (Kyebambe et al., 2017). For example, Upham and Small (2010) generated co-citations using the ISI database from 1999 to 2004 to identify the most prolific emergent research topics, and Porter et al., (2019) illustrated an implemented algorithm to calculate emergence scores from topical keywords in abstract records and elucidated steps in the process of generating research and development (R&D) indicators to highlight 'hot topic' terms and key players (Figure 2).

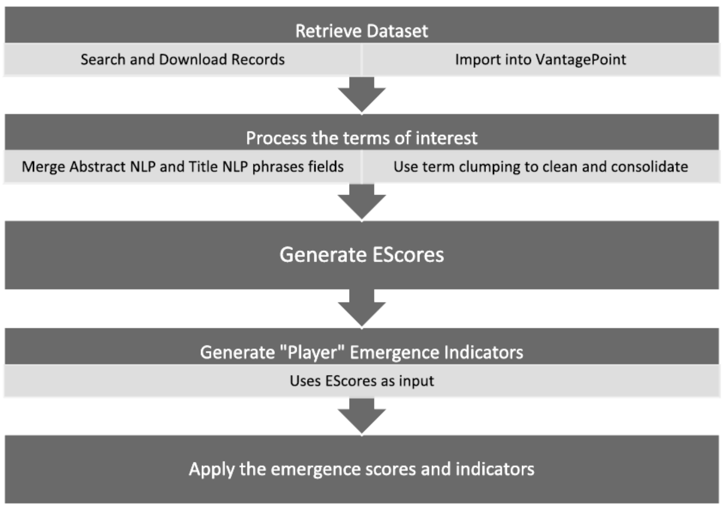

Figure 2 Broad outline of the process of generating emergent R&D indicators. (Porter et al.,2019)

In this study, we propose a novel approach to detail trends and emergent topics related to chitosan technology using academic analysis (i.e., citations and key words) and emergent scores. The emergence indicator offers insights for technology managers to forecast and make informed decisions for project development.

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3 Methodology and Data

This study applied a bibliometric predictive intelligence (BPI) model adapted from the emergent technology identification approach published in Porter et al. (2019) and Wang et al. (2019) to forecast technology convergence related to the chitosan biopolymer (Figure 3).

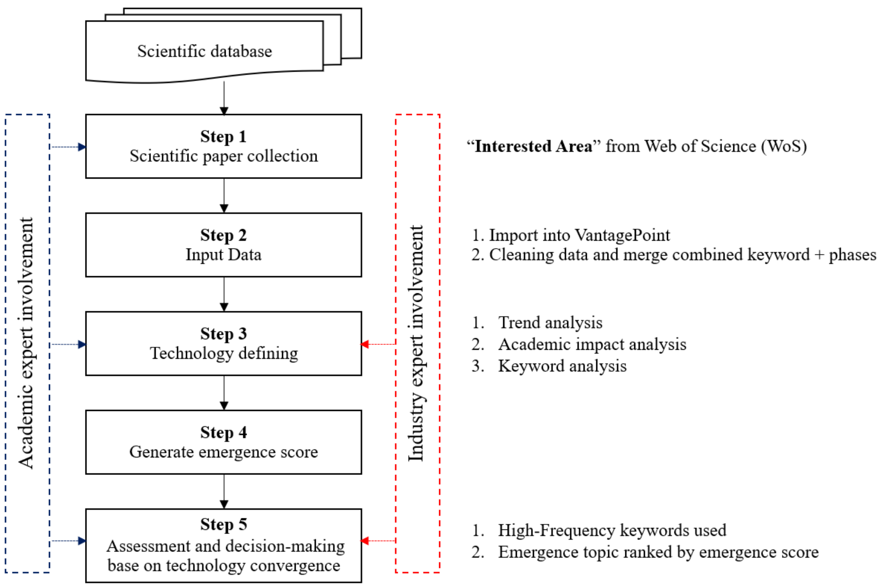

Figure 3 The *bibliometric predictive intelligence* (BPI) framework

The process began by retrieving a set of research related to chitosan in scientific paper publication records from the Web of Science (WoS) database using several queries suggested by an academic expert. A total of 2,612 scientific papers published from 2010 to 2019 were retrieved from the database. All articles were subjected to text-mining, whereby VantagePoint software version 12.0 was utilized to identify trends and emergent topics related to chitosan by extracting keyword patterns or relationships, after which the data were cleaned and keywords and phrases (title and abstract) were merged before running the results. Next, the preliminary technological patterns identified by the software were interpreted and defined by analysing annual published paper trends, academic impact, and keywords. The outcomes were again analysed by researchers and academic and industry experts. Fourth, we calculated emergence scores from the combined keywords and phrases, for which the 10 years of data were divided into a 3-year base period followed by a 7-year active period. The topics were ranked and tallied according to scores greater than 1.77 to identify research publications with high levels of emergence content (Porter et al., 2019, Wang et al., 2019). Finally, the upcoming technology was assessed based on trend analysis and emergent topics, which were ranked by their emergence scores. The technology convergence results were interpreted by academic and industry experts to ensure alignment with current and recent trends.

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4 Results and Discussion

4.1 Characteristics of chitosan applications

4.1.1 Annual tally of scientific papers

Diachronic changes in the number of papers on chitosan can reflect the development of relevant research in this field. The final dataset consisted of 2,612 papers on the topic of chitosan from the WoS. Trend analysis revealed striking features in exponential terms. Figure 4 illustrates that an average of 200 papers on chitosan were published annually from 2010 to 2015; however, that number increased by 75% from 2016 to 2019, with a peak of 350 papers in 2018. The significant increase in publications during the last few years reflects the intensification of research in this sector, which in turn illustrates the potential of technological goals to stimulate socially responsible research. These results demonstrate that chitosan-related technologies have become the subject of growing attention, and researchers are increasingly investigating this topic.

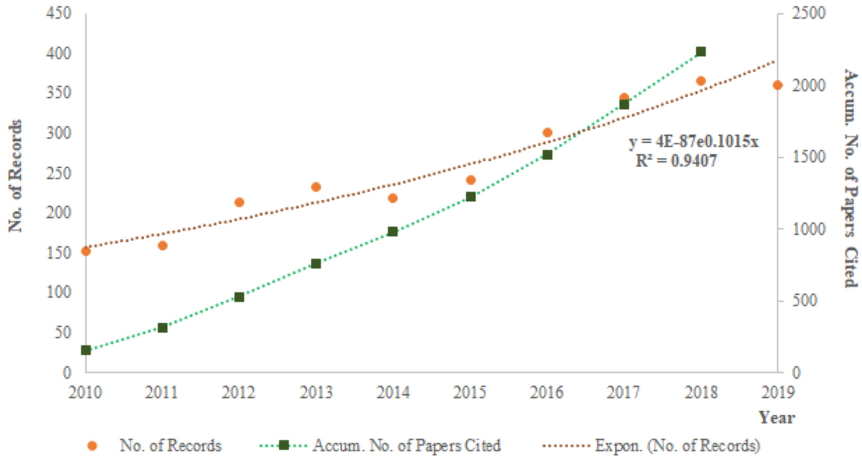

Figure 4 Annual distribution of papers and citations on chitosan applications

4.1.2 Analysis of academic impact

Citations are an effective means to measure articles' academic impact as well as intelligibly demonstrate diachronic changes in the literature. According to the WoS Core Collection, articles on chitosan have exhibited a substantial increase of citation impact in recent years. As Figure 4 shows, 85% (n = 2,230) of the 2,612 papers identified in this study were cited. Such a large proportion of citations is an important indicator of both current and future academic achievements of this field.

As a general rule, the most frequently cited papers are identified as landmark studies. Table 1 presents the five most-cited papers from 2010 to 2019. The study 'Chitosan-A versatile semi-synthetic polymer in biomedical applications' ranked first with 1,337 citations since 2011, followed by 'Biomaterials based on chitin and chitosan in wound

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dressing applications' with 804 citations over the past nine years. The predominant chitosan applications extracted from these articles' keywords include drug delivery, gene therapy, bioimaging, hydrogels, nanofiber membranes, scaffolds, sponges, and wound dressings.

The remaining three articles on the list ('Biomedical applications of chitin and chitosan based nanomaterials-A short review,' 'Novel chitin and chitosan nanofibers in biomedical applications,' and 'Current views on fungal chitin/chitosan, human chitinases, food preservation, glucans, pectins and inulin: A tribute to Henri Braconnot, precursor of the carbohydrate polymers science, on the chitin bicentennial') were each cited more than 400 times, which indicates that their associated keywords are also highly applicable to research in this field.

Table 1 The top five most-cited papers from 2010 to 2019

Title	*Keywords*	*Journal*	*Times Cited*	*Year*
Chitosan-A versatile semi-synthetic polymer in biomedical applications	Chitosan, Tissue engineering, Drug delivery, Gene therapy, Bioimaging	Progress in Polymer Science	1,337	2011
Biomaterials based on chitin and chitosan in wound dressing applications	Chitin, Chitosan, hydrogels, membranes, Nanofibers, Scaffolds, Sponges, Wound dressing	Biotechnology Advances	804	2011
Biomedical applications of chitin and chitosan-based nanomaterials-A short review	Cancer diagnosis, Chitin, Chitosan, Drug delivery, Nanocomposite Scaffolds, Nanofibers Nanoparticles, Tissue engineering, Wound healing	Carbohydrate Polymers	614	2010
Novel chitin and chitosan nanofibers in biomedical applications	Biosensors, Chitin Chitosan, Drug delivery, Filtration Nanofibers, Tissue engineering. Wound healing	Biotechnology Advances	560	2010
Current views on fungal chitin/chitosan, human chitinases, food preservation, glucans, pectins and inulin: A tribute to Henri Braconnot, precursor of the carbohydrate polymers science, on the chitin bicentennial	Chitin, Chitin digestion. Chitosan, Food preservation, Fungi, Human chitinases, Inulin, Pectin	Carbohydrate Polymers	425	2012

The citation impacts of scientific articles are often highly uneven, even within the same journal. Garfield (2006) studied the history and meaning of impact factors and confirmed the well-known 80-20 rule whereby the top 20% of journal articles receive 80% of the total citations.

Figure 5 illustrates results for a comparison of the total number of papers versus the number of citations per paper. The average citations per paper is about 21.12, and 711 (25%) articles received a higher number of citations. Our analysis revealed that 29.9% of the articles account for 80% of total of citations in this field (n = 55,187) during the study period. Such high percentages indicate a trend of intensifying research in this field and strongly suggest that chitosan will continue to be a major focus of future technological development.

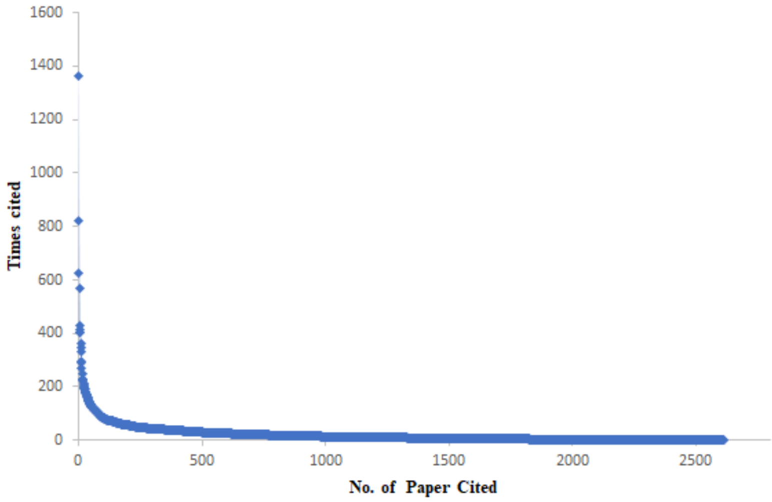

Figure 5 Number of papers versus times cited per paper

4.1.3 Distribution of publication output in journals

Examining the range of journals responsible for publishing the most frequently cited articles in different scientific fields is a useful exercise for tracking emergent research. Bradford's law states that most published papers in a given subject or field are concentrated in only a few academic journals. Table 2 lists the top five journals that published work related to chitosan, which can be regarded as the core periodicals focused on this topic. We can see that *Carbohydrate Polymers*, which has an H index 172(Q1), is the preminent periodical in the field of chitosan application, having published 203 (7.77%) related papers, followed by *International Journal of Biological Macromolecules* (H index 101; Q1), which published 188 papers (7.2%). In addition, *Journal of Applied Polymer Science*, *RSC Advances*, and *Food Chemistry* account for 2.14%, 1.53%, and

1.03% of the total volume of published papers, respectively. Polymers and plastics and medicine are the most common subjects of focus in these five core journals.

Table 2 The top five journals published in the field of chitosan research

Journal	*No. of Articles*	*Subject Categories*	*H Index*
Carbohydrate Polymers	203	Organic Chemistry, Materials, Chemistry, Polymers and Plastics	172
International Journal of Biological Macromolecules	188	Biochemistry, Molecular Biology, Structural Biology, Medicine (miscellaneous)	101
Journal of Applied Polymer Science	56	Chemistry (miscellaneous), Materials Chemistry, Polymers and Plastics, Surfaces, Coatings and Films	149
RSC Advances	40	Chemical Engineering (miscellaneous), Chemistry (miscellaneous)	113
Food Chemistry	27	Food Science, Analytical Chemistry, Medicine (miscellaneous)	221

4.1.4 Research subject analysis based on keywords

The research hotspots of chitosan application were explored by analysing high-frequency keywords. In general, keywords tend to both summarize the contents of a research article and refine and concentrate the most essential concepts related to the main topic. Figure 6 shows the top 100 keywords in chitosan-related papers identified through bibliometric analysis. Font sizes of the terms increase according to greater frequency during the past 10 years. A tally of keywords in top 100 appearing more than 30 times during the study period. The top 10 keywords related to this field are chitosan, nanoparticles, chitin, in-vitro, adsorption, drug-delivery, films, antibacterial activity, delivery, and antimicrobial activity, which account for 12.88%, 3.60%, 2.87%, 2.77%, 2.61%, 1.79%, 1.78%, 1.56%, 1.54% and 1.42% of the total 9,000 keywords, respectively.

Figure 6 Word cloud of the top 100 keywords related to chitosan applications

4.2 Identification of emergent topics

To identify emergent topics related to chitosan applications from 2010 to 2019, we used a 10-year test period consisting of a 3-year base period plus a 7-year active period and applied a threshold of 1.77 to extract terms with high emergent scores (Porter et al., 2019, Wang et al., 2019). Table 3 presents the top 10 high emergence scores according to topic. The study identified four major emergent topics related to technology convergence: 1) shelf life (extending the shelf life of fresh food); 2) regenerative medicine (raw materials for anti-aging); 3) therapeutic agents (raw materials aiding in drug delivery); and 4) antioxidant capacity (coating substances in food packaging). High emergent scores provide a sense of frontier R&D interests as well as organizational strategic directions and industry opportunities in a given domain. As identified by our experts, four potential industries for chitosan application related to the emergent topics comprise healthcare, cosmetics, agriculture, and food and beverages.

Table 3 The top 10 high emergence score terms related to chitosan applications

Emergent Topics	*Score*
Shelf life	7.17
Regenerative medicine	6.35
Therapeutic agents	5.19
Antioxidant capacity	4.98
Chemical properties	4.81
Weight loss	4.76
Composite films	4.46
Electrospun nanofibers	4.45

Water contact angle	4.42
Chemical modification	4.39

We used VantagePoint's PCA (Principle Components Analysis or 'factor map' routine) to cluster all emergent terms in the dataset during the study period. As illustrated in Figure 7, the PCA routine denoted 20 highly emergent topics, which we can predict to be most likely to remain particularly active over the next two or three years. The lists beneath the headings represent major terms related to the emergent topics.

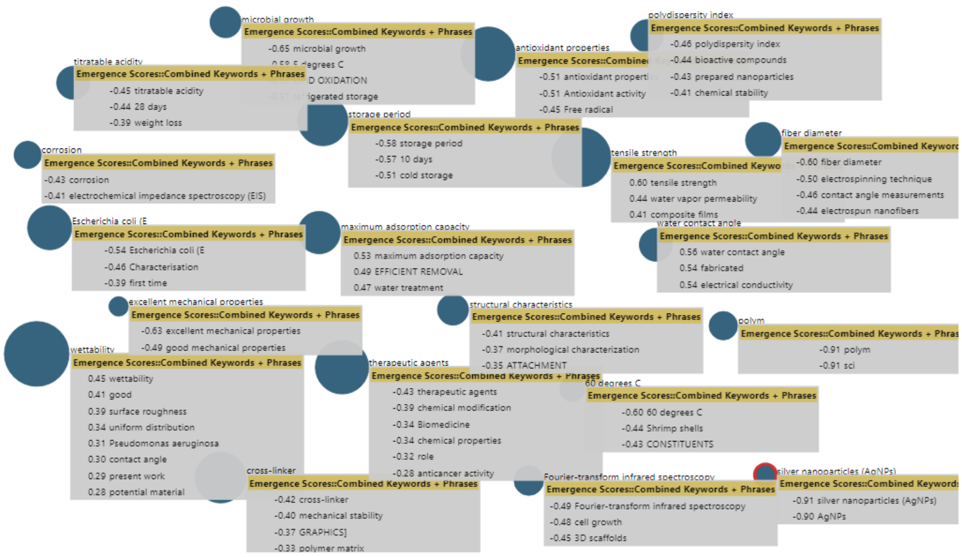

Figure 7 Emergent topics related to chitosan applications from 2010-2019

For the purpose of validation, we provide a projection of the two topics receiving the highest scores in terms of market size, namely shelf life and regenerative medicine. As reported by MarketsandMarkets (2018), the shelf life market was valued at USD 3.39 billion in 2018 and is forecasted to reach USD 4.76 billion by 2023 based on a compound annual growth rate (CAGR) of 7.0% (Figure 8a). This trend can be interpreted to predict upcoming technological developments for chitosan applications. Shelf life technology is being applied in the agricultural and food and beverage industries, and the growth forecast is based on the projected demand for packaged and convenient foods.

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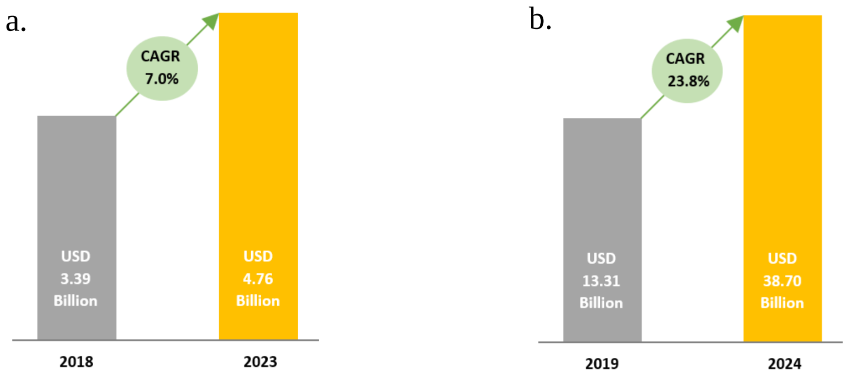

Figure 8a. The shelf-life market (MarketsandMarkets, 2018), **8b.** The regenerative medicine market (MarketsandMarkets, 2019)

The use of chitosan for regenerative medicine technology obtained the second-highest emergent score ranking; however, both the current and projected market size of this area are significantly higher than those of shelf-life. MarketsandMarkets (2019) projected that the market size of this industry to rise from USD 13.3 billion in 2019 to USD 38.7 billion by 2024 at a CAGR of 23.8% (Figure 8b). This emergent topic is a prime area for future investment, as fundamental knowledge of this technology is ready for implementation. Growth in this market is largely driven by the introduction of the 21st Century Cures Act by the US Food and Drug Administration (FDA), which increased funding for regenerative medicine research such as the development of chimeric antigen receptor T-cell (CAR-T) therapies amid increasing demand for the treatment of cancers, orthopedic disorders, and chronic wounds, among others. In addition to healthcare, regenerative medicine technology has been increasingly applied in the cosmetics industry.

5 Academic and practical implications

The results of the above-reported case study of chitosan applications based on the research framework of the *bibliometric predictive intelligence (BPI)* model can help fulfil organizational and academic goals to identify major gaps in technological development research and products over the next few years. The BPI approach agglomerates fuzzy database output to provide useful information for strategizing directions of technological development resulting in innovative products. The findings are informative for both academic and practical contributions.

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5.1 Academic implications

This study contributes to research on BPI as a viable approach for forecasting technology convergence. The model appears to be valid in the case of biopolymer technology, particularly chitosan, and a number of emergent technologies using this material can be predicted in accordance with recent market trends. Researchers can further adapt the model to fortify steps or algorithms for efficiently searching, analysing, and presenting results. In summary, this novel methodology can be an effective tool for technology convergence and can be further developed to predict upcoming technological developments.

5.2 Technological and business implications

5.2.1 New technology trends

The findings reported herein can help identify upcoming technological developments to provide companies with a comprehensive perspective of emergent topics for future business expansion. Companies can make informed decisions for R&D investment related to highlighted technologies to gain a competitive advantage as first movers in the market. In addition, in accordance with the Ansoff model of strategic management, firms can utilize industry-relevant information to identify opportunities in both existing and new markets (Al-Bostanji and Ghaleb, 2015). Existing firms as well as new business seekers can apply technology convergence to find niches for innovative products to meet customer demand. Moreover, this technique can confer benefits to drive the competitiveness of national economic growth and enhance people's well-being through the development of cutting-edge products and services.

5.2.2 New business trends

This study demonstrated the utility of technological convergence to identify emergent topics related to diverse chitosan applications for products and services in the healthcare, cosmetics, agriculture, and food and beverage industries. Using chitosan as a raw material, companies can combine existing business with emerging trends by generating new products or services or devising innovative ways to develop existing items. Companies can forecast upcoming business trends based on the size of global markets using chitosan as a raw material. This research identified multiple emergent topics and high-frequency words, which companies can use as a basis to study product feasibility and inform future investments. Organizations can direct the development of cutting-edge products and services in alignment with emerging business trends to gain a competitive advantage as first movers in expanding markets. Exploiting new business trends in chitosan applications not only strengthens economic growth, but also benefits the environment in terms of transforming waste from the fishery industry, particularly shrimp shells, into viable products or services.

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6 Conclusions

This study constructed a bibliometric predictive intelligence (BPI) model of emergent technology identification to forecast technology convergence related to the chitosan biopolymer. Relevant scientific papers were collected from Web of Science (WoS) using several queries, which were used as input data to analyse upcoming technological developments. The study identified the 10 highest frequency keywords (chitosan, nanoparticles, chitin, in-vitro, adsorption, drug-delivery, films, antibacterial activity, delivery, and antimicrobial activity) during the past decade. The results indicate major areas for the concentration and refinement of core ideas of this research topic. As interpreted by academic and industry experts as indicators of upcoming technological developments, the study also revealed the four major emergent topics related to technology convergence, namely shelf life, regenerative medicine, therapeutic agents, and antioxidant capacity, as well as the four potential industries of healthcare, cosmetics, agriculture, and food and beverages.

Overall, the identified sources provide a fruitful database to generate research insights leading to advanced technological applications. The growing number of papers on chitosan published during the last few years reflects the intensification of research in this sector, which in turn illustrates the potential of technological goals to stimulate socially responsible research. The top 10 keywords and four major topics are likely to remain particularly active areas for relevant companies to devote their technological development efforts. Companies and researchers can invest in developing the technological means to develop multiple uses for chitosan, thereby earning revenue while simultaneously contributing to environmental sustainability.

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