Computers & Industrial Engineering 183 (2023) 109475

Contents lists available at ScienceDirect

Computers & Industrial Engineering

journal homepage: www.elsevier.com/locate/caie

Leveraging blockchain to improve nutraceutical supply chain resilience under post-pandemic disruptions

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ARTICLE INFO

Keywords:
Supply chain resilience
Pandemic disruptions
Blockchain technology
Nutraceuticals industry
Bottleneck

ABSTRACT

Due to the pandemic, there has been an increase in the use of dietary supplements to boost the body's immune system. A demand–supply mismatch exists as a result of the unexpected increase in demand. The nutraceutical industry has been working on mechanisms to improve manufacturing efficiency and address bottlenecks in sourcing and production. The current study is attempting to address the issue of identifying these bottleneck problems by proposing a mathematical model to devise the optimal costs associated with the operations, as well as attempting to see the possibility of blockchain technology adoption as a better alternative to addressing these bottlenecks. The study compares adding an assembly line to existing infrastructure to implementing blockchain technology to improve manufacturing process efficiency. The study increases the likelihood of blockchain technology being used in the nutraceutical industry and calls for more research at the intersection of blockchain, nutraceuticals, and optimization.

1. Introduction

"The value of an idea lies in the using of it." Thomas Edison (1847 – 1931), Inventor.

Nutraceuticals, or dietary supplements, have played an important role in maintaining our immunity and overall health (Knight, 2000). The increased use of nutraceuticals to keep our health in peak condition prompted researchers to work on improving the nutraceutical supply chain mechanism (Szentesi et al., 2021). Technology has improved the efficiency of logistics and supply chain mechanisms in the nutraceutical sector (Yee-Loong Chong et al., 2015), making nutraceuticals more accessible than ever before by reducing waste at various stages of manufacturing and delivery of goods to retail outlets (Parfitt et al., 2010).

As a result of the increased accessibility and consumption of nutraceuticals or dietary supplements, India's dietary supplement or nutraceutical industry is poised to become one of the world's largest (EY Report, June 2022). Nutraceuticals (naturally derived products that provide additional health benefits in addition to the basic nutritional component found in food) have a current market value of Rs. 650 crores (India - Nutraceutical Market Value 2017–2022). According to the report, the pandemic has made people more aware of their health, and taking care of their health has become a priority. This habit of prioritising health has resulted in an increase in the consumption of dietary supplements, or nutraceuticals (Jauhar et al., 2013). The nutraceutical industry is an effective confluence and combination of food, pharma, Ayurveda, and technology that has proven its efficacy in safeguarding and enhancing an individual's health on a regular basis (https://www.ETHealthworld.com, 2022). The effectiveness of the aforementioned factors would increase mass adoption of nutraceuticals and their market share (Lohmer & Lasch, 2020).

The pandemic, has made people more aware of their health, and taking care of their health has become a priority. This habit of prioritising health has led to an increase in the use of dietary supplements, also known as nutraceuticals (Jauhar et al., 2014; Prajapati al., 2022). The traditional nutraceutical supply chain is beset by a number of issues, including a lack of transparency, difficulties in monitoring supplies, a general lack of trust, the distribution of out-of-date medications, and so on (Augustin & Sanguansri, 2012). Nonetheless, this industry must record and maintain reliable information about the sourcing, sorting, and mixing of active pharmaceutical ingredients (APIs), as well as manufacture supplements in accordance with the relevant authority's guidelines, and improve its agility in delivering nutraceuticals to the market for sale to end users (Jauhar et al., 2013; Murugesan al., 2021).

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https://doi.org/10.1016/j.cie.2023.109475

Available online 26 July 2023

Nutraceuticals are in charge of our health and well-being, and they are also used as preventative medicine (Malve, 2022).

This class of drugs saves many lives and contributes to the growth of any nation, both tangibly and intangibly. Drug companies invest heavily in research and development in order to introduce new dietary supplements (Safaei, 2020). They would want to streamline and optimise their resources in order to get the most out of the infrastructure that is available. Customers' increased awareness has increase the demand for nutraceuticals (Pratap et al., 2022; Jauhar et al., 2022). The unexpected surge in demand for nutraceuticals may cause systematic and ad hoc bottlenecks that stymie production, resulting in the loss of business opportunities (Diaz et al., 2022).

As a result, the purpose of this research paper is to go over the methodology for identifying and mitigating bottlenecks in the nutraceutical industry using blockchain technology. The nutraceuticals or dietary supplement industry is divided into three broad areas for implementing and incorporating blockchain into the value chain: sourcing of raw materials, manufacturing, and final distribution of finished products, from the warehouse on the factory premises to delivery of the final product to end consumers.

A recent surge in blockchain-related studies, initiatives, and discussions has piqued the interest of both researchers and practitioners (Hao et al., 2021; Spieske & Birkel, 2021; Ding et al., 2021; Shi, 2022; Bai & Sarkis, 2022). The distributed ledger technology's decentralised database, which enables the efficient, permanent, and verifiable recording of transactions, has been viewed as a promising solution to the industry's bottlenecks. Blockchain technology can be used in the manufacturing process to identify and resolve bottlenecks due to its security features and ability to access information stored remotely (Biswas & Gupta, 2019; Azzi et al., 2019). The blockchain platform is used to store information about raw material sourcing, vendor information, and the time required to transport the material from the vendor to the warehouse for processing into the final product. The raw material will then go through several stages of processing before being transformed into the finished product (Upadhyay et al., 2021; Aoun et al., 2021; Yadav et al., 2022).

The blockchain stores data on the time, duration, input materials, and cost of raw material processing. The appropriate authority can interpret the data to identify bottlenecks. Once the bottlenecks have been identified, they can be addressed and corrected to improve system efficiency (Fan et al., 2018). Zhao et al. (2022) emphasises the importance of information sharing, which includes accurately forecasting demand on which to base manufacturing. Thus, losses due to inaccurate prediction can be avoided by collecting and sharing information, which is made simple by blockchain technology.

The distribution of finished products to the warehouse for distribution to retail stores for sale is the final step in any manufacturing process. Blockchain can also be used to track shipments and ensure they arrive on time at retail outlets. Blockchain technology can be used to track and prevent product diversion to the grey market, resulting in artificial scarcity. The main reason for interest in blockchain is the security it provides during transactions, as well as anonymity and data security without the involvement of a third party. According to Wang et al. (2022), the cost of implementing blockchain technology should be less than the cost of losing consumer trust. The primary goal of blockchain technology is to increase system transparency by storing and sharing data for further analysis. As a result, the research seeks to find a balance between the extent to which blockchain technology can be implemented and the consumer trust that the organisation can gain as a result of the technology's implementation.

Our research examined the utility of blockchain throughout the nutraceutical manufacturing process, from raw material sourcing to the delivery of finished products to retail outlets. In the paper, the case study methodology has been used, with a case study built using the forecast of demand for nutraceuticals in the post-pandemic era. The current supply chain issues has then been thoroughly investigated, with a focus on existing and potential bottlenecks. The paper's main focus would be on using blockchain technology to reduce and eliminate bottlenecks. The paper would also propose a blockchain implementation model for the effective implementation and integration of blockchain technology into existing manufacturing processes with minimal teething problems.

To investigate the extent of blockchain technology adoption in the nutraceutical industry, the paper employs a two-tier methodology. To begin, it divides the nutraceuticals manufacturing process into three broad stages: sourcing raw materials, manufacturing, and final distribution of finished products from factory premises to end consumers. It also identifies potential bottlenecks in each phase and investigates whether blockchain adoption can help mitigate these bottlenecks. To strengthen the idea of blockchain adoption in the nutraceutical sector, the paper conducts a comparative study by creating two realistic scenarios. The first scenario involves adding a new assembly line to increase production capacity. The second scenario, on the other hand, employs blockchain technology to boost manufacturing efficiency. According to the findings, the second scenario of blockchain adoption is less expensive than adding another assembly line.

The study has broad implications for the nutraceutical industry because it provides an initial overview of the optimization problem by comparing the costs associated with both scenarios. The primary objectives of this paper are to: (1) Determine the value of blockchain technology in resolving bottlenecks in the sourcing, manufacturing, and distribution of nutraceuticals, (2) Propose a solution to the bottleneck, (3) To develop a mathematical model to support the incorporation of blockchain technology into the current process and (4) To investigate the benefits of blockchain technology in terms of traceability, efficiency, data security, and agility over traditional methods such as adding an assembly line to meet the demand for nutraceuticals in the post-pandemic era.

The paper is organised as follows to achieve the aforementioned objectives: Section 2 investigates the literature on the evolution of dietary supplements, supply chain risks in the nutraceutical and pharmaceutical industries prior to and following the pandemic, and how blockchain technology can be used in dietary supplement manufacturing. Section 3 discusses research gaps for blockchain technology implementation and the research paper's intended contribution, while Section 4 discusses problem identification, which uses a case study approach to determine the depth and severity of the problem. Section 5 discusses the Solution approach after identifying blockchain technology as the best alternative. Section 6 goes over the discussion, Section 7 goes over the managerial implications, and Section 8 goes over the conclusion, limitations, and future research direction.

2. Literature review

The section examines prior research on the evolution of dietary supplement and pharmaceutical supply chain mechanisms. Table 1 depicts recent research on the mechanisms of dietary supplement and pharmaceutical supply chains. The literature review focuses primarily on the dietary supplement supply chain and supply chain risks, which are the primary causes of bottlenecks, interrupting the supply of dietary supplements or nutraceuticals to final customers. The review then focuses on the use of blockchain technology to improve the supply chain and manufacturing processes in the nutraceutical and pharmaceutical industries.

2.1. Evolution of the supply chain for dietary supplements

Clauson et al. (2018) states post reviewing various forms of literature available and conclude that blockchain technology can be used to manage and to address various critical situations and conditions which are linked with healthcare/nutraceutical supply chain. Cederberg et al. (2019) emphasise the importance of high-quality, environmentally friendly food that is sourced sustainably. To source the product

Table 1
Recent research on dietary supplement and pharmaceutical supply chain mechanisms.

S. No.	Citation	Methodology	Contribution	Key Insights	Key Learnings
1	Haakonsson et al. (2013)	Co-evolutionary Theory	The paper proposes a co-evolutionary methodology for combining the best of both worlds to leverage the potential of the Indian pharmaceutical industry.	The paper uses previous constructs derived from previous research about the adoption of best practices in terms of environmental sustainability and locational advantage to meet the business needs in a better way.	The potentiality of the Indian pharmaceutical industry has attracted many new companies into the market, and they are combining international and national standards for increasing efficiency and value proposition.
2	Renna (2013)	Decision models based on private neutral networks with a network mediator where a set of organisations are allowed to negotiate and interact	The paper highlights the fact about the need of the organization to adapt to the rapidly changing business environment. The paper proposes a simulation where the stakeholders or partners in the supply-chain or any other similar network changes at short term intervals and what impact does the change has on the stake-holders of the entire network.	The paper proposes a methodology or decision model for business entities to determine whether or not to participate in the local network without sharing any information and based on localised knowledge. The paper tells us about how the changes in the business environment affect the decision-making process for various stakeholders in the network.	The paper tells us that a decision that is beneficial for others might not be helpful for one particular stakeholder, especially where there is no information sharing among the parties to the supply chain mechanism. The paper empowers the various stakeholder groups of the SCM; they are free to choose to implement blockchain technology as a part of their process if they find it beneficial.
3	Zheng et al. (2017)	Empirical/Informational	Blockchain is the foundation of bitcoin and forms an immutable ledger where transactions take place in a decentralised manner.	The security aspect of blockchain finds its usage in fintech, financial transactions, the internet of things, and other transactions where security is of utmost importance.	There is still a problem with the implementation of blockchain technology in terms of scalability. However, there have been some advances in recent years to overcome these challenges, and there have been continuous attempts to maximise the usage of blockchain technology in various sectors.
4	Hughes et al. (2019)	Bibliometric and case-study approach	Despite the potential of blockchain technology for its security and widespread usability, it is finding little to no usage in IT systems and information management literature.	The paper uses the literature review technique to analyse the current trends in the application of blockchain technology in various industries and sectors.	This analysis of the body of literature highlights that, although few commercial-grade blockchain applications currently exist, the technology demonstrates significant potential to benefit a number of industry-wide use cases. This study expands on this point, articulating through each of the key themes to develop a detailed narrative on the numerous potential blockchain applications and future direction of the technology while discussing the many barriers to adoption.
5	Grover et al. (2019)	Systematic Literature Review and Social Media Analytics	The paper uses systematic literature review and extensive research on social media to identify the buzz around blockchain technology and how many industries have absorbed the technology to increase their operational efficiency.	There are many research questions, like how the technology has been implemented in various industries and how the industries have been responding to the changes because of the implementation of these changes into their business processes.	The findings from the literature review are divided into answering three research questions that were asked first. Mainly the finance and retail industries are implementing blockchain technology, and there is immense scope for other industries to implement it and create disruption. The blockchain has been successful in eliminating intermediaries, reducing distrust amongst the stakeholders in the value chain, and increasing security.
6	Bumblauskas et al. (2020)	Case Study	The paper takes a case study approach to implementing blockchain technology for delivering eggs from farm to consumer by a company based in the Midwestern USA.	The paper explores ways of implementing blockchain to increase the transparency and efficiency of the global supply chain mechanism. It uses the Internet of Things, or IoT, to track and trace the movement of goods.	With the increase in trackability and traceability of products, consumers will make informed choices and adopt sustainable practises faster than ever before.
7	Bai & Sarkis (2020)	Hesitant Fuzzy set and Regret Theory and Systematic Literature Review	Blockchain technology is effectively used to increase the transparency of supply chain mechanisms. But uncertainty and an emphasis on sustainable transparency	Key insight regarding the effective implementation and transparency of the blockchain is given. Like the partners across the value chain, they need to be in sync and participate in implementing the technology.	The advantages of blockchain technology are highlighted in the paper. The hesitant fuzzy set and regret theory are used for unexpected utility models. These two methodologies, along with the systematic literature review, were used in the paper to highlight the advantages of blockchain technology and why it should be

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Table 1 (*continued*)

S. No.	Citation	Methodology	Contribution	Key Insights	Key Learnings
					incorporated into the supply chain mechanism.
8	Kamble et al. (2020)	Systematic Literature Review	The paper highlights the lack of transparency and efficiency in the supply chain of agrifood. It also shows how new and emerging technologies like the Internet of Things, blockchain, and big data are potential enablers of sustainability in the agri-food business.	These technologies are driving the agricultural business into a sustainable and transparent business that is data-driven.	The main aim of the paper is to analyse and understand the level of analytics (descriptive, prescriptive, or predictive) used to develop a sustainable supply chain in terms of social, environmental, and economic aspects. Based on the literature review, key insights were developed that enabled the deployment of resources at an important juncture of the supply chain processes.
9	Fosso Wamba et al. (2020)	Survey and hypothesis development/USA and India	The paper examines the potential influence of blockchain on supply chain mechanisms. The rate of technology adoption and influence of blockchain technology on developing and developed countries were studied.	The hypothesis developed was validated using the survey, and the results were tested using the classical structural equation modelling framework.	The behaviour of the managers in real life changed based on the effectiveness of the blockchain technology in the supply chain mechanism. Blockchain technology increases transparency in transactions and increases supply chain performance. The literature highlights the importance of supply chains in the most modern businesses and how knowledge sharing plays an important role in spreading awareness regarding new technologies.
10	Lohmer et al. (2020)	Simulation model	The impact of promising applications with respect to the agent-based simulation model helps us understand the importance of blockchain technology in supply chain networks.	The paper speaks about the importance of supply chain resilience and the efficiency that blockchain technology brings to the overall system. The paper also discusses various scenarios where blockchain can enable vertical and horizontal integration of the value chain.	The paper weighs the cost of disruption in the supply chain framework and advocates for the faster adoption of blockchain technology as a key medium for constituting a resilient blockchain framework. This can be done through effective collaboration on blockchain technology and proper knowledge sharing to spread awareness about blockchain and its benefits in building a resilient supply chain framework.
11	Choi et al. (2020)	Bibliometric study	Blockchain technology is a potentially disruptive force that has the potential to disrupt many business operations and change the norms of existing businesses.	The parameters on which supply chain operations management depends and are included in this paper are social influence, online reviews, advertising and marketing promotions, logistics management, forecasting, risk analysis, product introduction and design, and medical treatment.	The paper, through the bibliometric study, has pointed out the key features of blockchain and the parameters on which the nuances of supply chain and operation management depend. The paper, through an extensive literature survey and bibliometric processes, determines the key themes that will aid the implementation of blockchain technology.
12	Ali et al. (2021)	Systematic Literature Review	The SLR presented a comparative study to analyse the advantages of blockchain technology across different sectors like government, finance, manufacturing, and healthcare.	The results from the systematic literature review were compared on three parameters, which are categorised as benefits, challenges, and functionalities, to enable professionals to adopt blockchain in a structured manner.	The study helps and empowers existing and future blockchain users to learn about and explore the true potential of blockchain technology, increasing the efficiency of the process.
13	Yousefi & Mohamadpour Tosarkani (2022)	Fuzzy Cognitive Maps and FSDEA	Blockchain technology, or distributed ledger technology, is a useful tool for improving the efficiency and transparency of the supply chain. It can be used for sustainable sourcing, lowering carbon footprints, and boosting traceability.	Even though there is a lot of usefulness in blockchain technology, due to a lack of familiarity with the technology, it seldom gets implemented in the industry.	The articles explore the enablers and barriers to implementing blockchain technology. The paper does an extensive literature review to search for barriers and enablers. It then uses the fuzzy-y cognitive map model to define each enabler. The model was used to prioritise each enabler and determine its impact on the supply chain mechanism. The results from these models are used to prioritise the blockchain enablers and integrate them into the existing supply chain mechanism.
14	Patrício et al. (2022)	Literature review of databases and articles to	The paper identifies the importance of collaborative networks (CN),	The critical success factors, which mainly comprise the quality of the	The paper highlights the importance of collaborative networks and how

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Table 1 (*continued*)

S. No.	Citation	Methodology	Contribution	Key Insights	Key Learnings
		identify the critical success factors	through the identification of critical success factors, which will form the basis for the formation of a suitable model allowing to interpret whether an organisation that is a part of a CN can add value to the overall network through the implementation of sustainability methodology.	goods produced or sold, market analysis and focus, and competitive advantage in the market, are a few of the cornerstones of the collaborative network, even though the concept of CN covers a very broad spectrum.	various organisations that are part of them can add value to the overall network. Similarly, if one organisation in the supply chain network implements blockchain technology, it won't be sustainable and produce tangible results and benefits unless the technology is implemented on an end-to-end basis, starting from the sourcing of raw materials to the distribution of finished goods to end customers. In other words, the article highlights the importance of joint and collaborative decisions for achieving a goal.
15	Current Study	Case Study Approach and Mathematical modelling	Identifying the bottlenecks in the sourcing, manufacturing, and distribution of finished goods in the nutraceutical industry and rectifying the bottlenecks using blockchain technology	The 3 stages of sourcing raw materials to distribution of final goods	

sustainably, a mechanism such as blockchain technology should be used to trace the source of the food. In the case of dietary supplements, traceability of raw material sources and recording of processing for end users is critical. The consumer takes the supplement because of the certification and the trust the company has built with them. As a result, the use of blockchain technology would increase customer trust in the brand and its products.

Rogerson & Parry (2020) highlights the utilization of blockchain technology beyond the domain of cryptocurrency. The technology is used to enhance the trust between the parties through the enhancement of visibility of the operations and sharing of information. May & Guenther (2020) emphasise the importance of material flow cost accounting, which calculates the monetary value of processes as well as the waste generated by those processes. Berry pomace, a byproduct of black currant juice production, is used as an example in the paper. Energy consumption and by-product generation in each procurement and manufacturing process can be traced and accounted for using blockchain technology. If the byproduct is useful, it can be upcycled into another product to generate additional revenue. Similarly, the manufacturing process for dietary supplements can be traced back to the source of raw materials, and wastage can be reduced, potentially lowering the price of the supplements and allowing for mass acceptance of dietary supplements.

Sunny et al. (2020), stresses on the traceability aspect of the blockchain technology which can be used to identify origin of the raw-materials and promotes information sharing. This sharing of information would allow for the increase in transparency within the supply chain mechanism. According to Cao & Shen (2022), the blockchain technology is responsible for allowing and accelerating the increase of sustainable products into the global market which are aligned with the Sustainable Development Goals led down by the United Nations. The blockchain technology would promote the usage and adoption of sustainable sources for the manufacturing of nutraceuticals.

Meng et al. (2022) propose process capability indices as another method for using radio frequency to test the quality of the supplier's product. By eliminating inferior products, the supplier can ensure that its products are of the highest quality. Two-phase processes are used to extract the highest quality products from the remaining items: data-filling and generalised p-testing (GE-P). When combined with blockchain technology to determine the purity and quality of the raw materials required, the two-phase processes would provide us with complete assurance about the sustainable sourcing of high-quality products.

2.2. Supply chain risk analysis in pharmaceutical industry before pandemic

According to the solutions, a stable supply chain not only helps the company improve its market share, but it also benefits customers by stabilising retail prices. According to Kelle et al. (2012), because the pharmaceutical industry accounts for a significant portion of the health sector, proper inventory management is critical. In the case of inventory management of medicines in hospitals, the paper considers reordering and lead and lag time of ordering medicines. The paper focuses on the priority-based ordering system and properly analysing medicine need and usage. Prioritization involves balancing three key performance indicators (KPIs): the expected number of daily refills, the service level or efficiency level, and storage space utilisation. To create a stable and resilient supply chain model.

In the presence of supply chain disruption risks, Sawik (2014) proposed a stochastic mixed integer programming approach to integrated supplier selection and customer order scheduling for a single or dual sourcing strategy. The paper considers two sets of suppliers: one local and reliable vendor, but sourcing from that vendor is more expensive than sourcing from a supplier located outside of the region. Because they are located in a different geographical area, the manufacturer may have little or no hold if the supplier fails to fulfil his commitment.

Torabi et al. (2015) propose a bi-objective mixed-probabilistic, two-stage stochastic programming approach to solving supplier selection and order allocation problems. Supply risk is highlighted as a component of overall organisational risk by Huang & Xu (2015). The company's two main risk-mitigation strategies for overcoming supply-chain uncertainties are dual sourcing and backup production. The paper creates a dynamic programming model to examine the feasibility of risk mitigation using these two approaches. According to Rajesh and Ravi (2015), humans can be exposed to a variety of external risks. As a result, choosing suppliers in this context is a qualitative as well as quantitative challenge. MCDM techniques are used in the paper to rank resilient attributes and prioritise the list of suppliers based on their sensitivity. The final list of disruptions is then computed and validated using AHP and ANP, allowing management to make informed decisions.

Hasani & Khosrojerdi (2016) focuses on the development of an uncertain mixed-integer and non-linear supply chain network model. Six resilience strategies for risk-related disruptions are identified in the paper. In addition to the model, a robust framework parallel to the Taguchi-based memetic algorithm is developed, which includes a customised hybrid parallel adaptive large neighbourhood search. Lücker & Seifert (2017) discusses the risk management problem of a major pharmaceutical company. Such risks can be reduced by creating a risk mitigation inventory, as well as dual sourcing and agility capacity. The relationship between the aforementioned constructs is examined in the context of a drug manufacturing company that faces supply chain modelling risk.

Nematollahi et al. (2017) investigate the simultaneous coordination of visit interval and service level in a two-echelon pharmaceutical supply chain with stochastic demand. The pharmaceutical manufacturer has complete control over the manufacturing and distribution of medicines to retailers, but the wholesale supplier of medicines has no control over the intervals at which the medicines are supplied to retailers for sale to end customers. The manufacturer is in charge of determining the quantity and lead time for manufacturing medicine.

2.3. Supply chain risk in pharmaceutical industry after pandemic

The pandemic and post-pandemic eras caused numerous changes in society's social fabric. People's overall health has increased the need for and demand for medicine. Nonetheless, numerous disruptions occurred during and after the pandemic era, affecting the overall demand for medicines. People are far more likely to take nutritional supplements to improve their overall health. So, after March 2020, the literature review will concentrate on the increased demand for dietary supplements and how manufacturers are innovating to mitigate the risks posed by the pandemic while also navigating supply chain disruptions to ensure smooth and hassle-free product supply to end consumers

The importance of accurate demand forecasting and its impact on the pharmaceutical supply chain is emphasised by Zhu et al. (2021). The paper proposes that time series data from other sources be borrowed and modified using various machine learning processes to complete the model for increasing supply chain efficiency.

According to Tat & Heydari (2021), unused medicines in hospitals and other locations can be distributed or used by people who do not have access to them, reducing inventory waste and pollution to the environment caused by improper medicine disposal. This paper employs a two-tiered PSC comprised of an upstream member who is the medicine supplier and a downstream member who is the pharma retailer to reduce the entry of medicine waste into the environment.

Hosseini-Motlagh et al. (2021) highlight the issue of unused medicine, which creates massive waste if not disposed of properly. These medications can be distributed to those in greatest need. The manufacturer or wholesaler should take back the residual stock from the retailer and donate some to people who actually need the medicine. From the standpoint of the retailer, the implementation of blockchain technology for the distribution of medicine or nutraceuticals would provide a competitive advantage because the retailer faces numerous competitors. In contrast, there aren't as many manufacturers available as there are retailers, so competition at the manufacturer level is lower than at the retailer level ((Niu et al., 2021).

Gao et al. (2023) propose using blockchain technology and artificial intelligence to efficiently and effectively coordinate the vaccine supply process to various stakeholders. The paper is written in the context of COVID-19, where time was of the essence and delays in vaccine delivery would have resulted in many more people becoming infected with the virus. As a result, the paper discusses the use of new technologies to accurately predict vaccine demand and prepare vaccines for delivery to patients.

2.4. Usage of blockchain technology in nutraceutical industry

According to Sauer & Seuring (2019), a triadic or tetradic multi-tiered supply chain model has recently been formed to address new and upcoming supply chain issues. This supply chain model is used when there is an upstream for obtaining raw materials and a downstream for processing the materials obtained. The same concept can be applied to the sourcing of raw materials via blockchain. Because of the multi-tiered supply chain, the process is monitored for efficiency and resource optimization. If there is a flaw in the system, such as a lack of clarity about where the product is sourced, it will be detected immediately while processing the stored data, and the system will be able to phase out the material of questionable origin.

Jabbour et al. (2019) conducts a literature review on the effectiveness of multi-tiered supply chain modelling. The paper emphasises that the current system has too many stakeholders, which complicates the mechanism. As a result, a multi-tiered supply chain is being developed in order to simplify the mechanism involving multiple stakeholders. This is where blockchain technology comes in, tracking and recording activity in the supply chain, which is extremely useful for quality checks and quality assurance in dietary supplement manufacturing. Garcia-Torres et al. (2019) emphasise the importance of traceability in achieving supply chain sustainability. One of the keys to producing a higher-quality finished product is sourcing dietary supplements in an environmentally responsible and sustainable manner.

Lohmer et al. (2020) investigate the competitive advantages of the dual sourcing policies of the manufacturing unit. The paper examines four distinct scenarios, each with its own source of disruption and information availability. A two-dimensional stochastic dynamic programming model is created based on the information provided to explicitly address the issue of which vendor and sourcing model to use. The end result will be a valuable resource for the manager, serving as a guideline for which decisions to make in order to maximise productivity.

Kouhizadeh et al. (2021) state unequivocally the link between a sustainable supply chain and blockchain technology. Blockchain technology has been at the forefront and has gained global attention due to its ability to revolutionise the supply chain mechanism. The traceability of the origin, as well as the securing and optimising of the process through blockchain technology, would save a significant amount of money that would otherwise have been spent on auditing the process and tracing back the raw materials to their origin. Chen, (2022) emphasises the importance of traceability and responsible raw material sourcing. These two elements are crucial in the manufacture of health and dietary supplements. The source of the raw materials should be investigated because it will affect the outcome or finished product. As a result, using blockchain to source raw materials and optimise processes for the manufacturing of dietary and health supplements is extremely advantageous, as it contributes to the industry's stringent quality standards.

According to Montecchi et al. (2021), increasing supply-chain transparency is critical for improved operational efficiency and resource utilisation. The article emphasises the importance of traceability and transparency in the supply chain mechanism through knowledge integration, governance, and sustainability. Blockchain technology, for example, can be used to achieve the transparency discussed in the paper. It stores information about the source, which can be analysed to determine whether the raw material's source complies with standard norms.

Parida et al. (2022) conducts a literature review to highlight the importance of Supply Chain Finance, which is currently becoming a major concern for buyers and suppliers all over the world. The stakeholders in the supply-chain mechanism were more concerned with its optimization and efficiency, but they did not consider the cost of implementing changes in the system to increase its efficiency. To implement blockchain technology into the supply chain mechanism for the manufacturing and distribution of nutraceuticals, a significant capital expenditure may be required, which may be a barrier to its implementation throughout the entire supply chain mechanism.

3. Research gaps and contributions

According to the review of literature, the blockchain has found utility in the sourcing of raw materials needed for product manufacturing. Green supply chain (Borroni et al., 2021) and sustainable raw material sourcing (Freitas et al., 2021) are concepts that would benefit the planet and all downstream components of the value chain. The information about the material's sourcing is stored in the chain's blocks.

The information about sourcing and supplying raw materials for finished goods is stored in encoded and encrypted blocks that are locked by a unique fingerprint known as a hash key (Karamchandani et al., 2021). Because each subsequent block of the blockchain stores the information of the previous block, decrypting a single block of the blockchain is impossible. As a result, it cannot be tampered with. If any of the blockchains is tampered with and data is extracted from them, the technology embedded within the blockchain records the tampering and sends the information to the appropriate authority for further audit. The ability to trace raw materials back to their original source is the primary benefit of blockchain technology.

Despite its advantages in material sourcing, blockchain technology is not used in the manufacturing of any goods. The paper looks into the feasibility of implementing blockchain technology in the production of dietary supplements, which is a thriving industry, especially in the post-pandemic era when people are much more concerned about their health and well-being. A surge in demand for dietary supplements would put a strain on existing manufacturing and distribution facilities. This increased demand for dietary supplements may result in a system bottleneck, lowering overall system output.

There has been limited research into the use of blockchain in the manufacturing process. The blockchain stores data about the manufacturing process in real time. This data can be compared and analysed with the system's output under ideal or designed conditions. The paper focuses on the process of identifying bottlenecks in the manufacturing system by comparing the information stored in the blockchain to the designed capacity of the manufacturing unit or specific machine. If the designed capacity is greater than the real-time output, the system may have a bottleneck.

To summarise, the paper's intended contribution would be the use of blockchain technology to mitigate and minimise bottlenecks in nutraceutical sourcing, manufacturing, and distribution. These are some examples:

1. Blockchain technology has the potential to improve efficiency in the manufacturing sector while utilising existing infrastructure.
2. Implement blockchain technology as a complete solution to the bottleneck in the sourcing, manufacturing, and distribution of finished nutraceuticals to their final customers.
3. To prevent bottlenecks from occurring in the system by utilising blockchain technology and mitigating bottlenecks before they occur.

To assess the feasibility of implementing blockchain technology in the nutraceutical sector in order to optimise the existing infrastructure and increase its efficiency in order to produce increased quantities of dietary supplements in response to the post-pandemic surge in demand.

4. Problem definition

Fig. 1 depicts the value chain of the nutraceutical industry at a crossroads. The diagram depicts the raw material being sourced from suppliers to the delivery of the finished product to retail outlets, where it is then sold to end users. Fig. 1 depicts a value chain with multiple stakeholders, starting with the person who sources the raw material and ending with the owner or proprietor of the retail outlet where the end customer purchases the nutraceuticals. The value chain includes multiple stakeholders as well as levels in both vertical and horizontal directions.

The multi-tiered value chain of the nutraceutical industry has numerous bottlenecks that reduce the chain's overall efficiency. Bottlenecks can occur as a result of a lack of communication among value chain stakeholders, inaccurate demand forecasting, inventory of raw materials and finished goods, changes in customer preferences, seasonality of demand, and other factors. Bottlenecks can also occur in the manufacturing unit, where multiple processes are used to convert raw materials into the final product, dietary supplements. As a result, some manufacturing steps may take longer than anticipated, limiting the capacity of subsequent manufacturing steps. A lack of clarity about the resources needed for each step—in terms of time, manpower, and other factors—can be a major source of bottleneck. The overall efficiency of the system would improve if there was a system that could store data and regularly transfer it to the appropriate authority for analysis of any anomaly that could lead to a bottleneck in the system.

A system with varying magnitude bottlenecks can employ a support or supervisory system to track and mitigate bottlenecks that impede system efficiency. The bottleneck problem is divided into two stages:

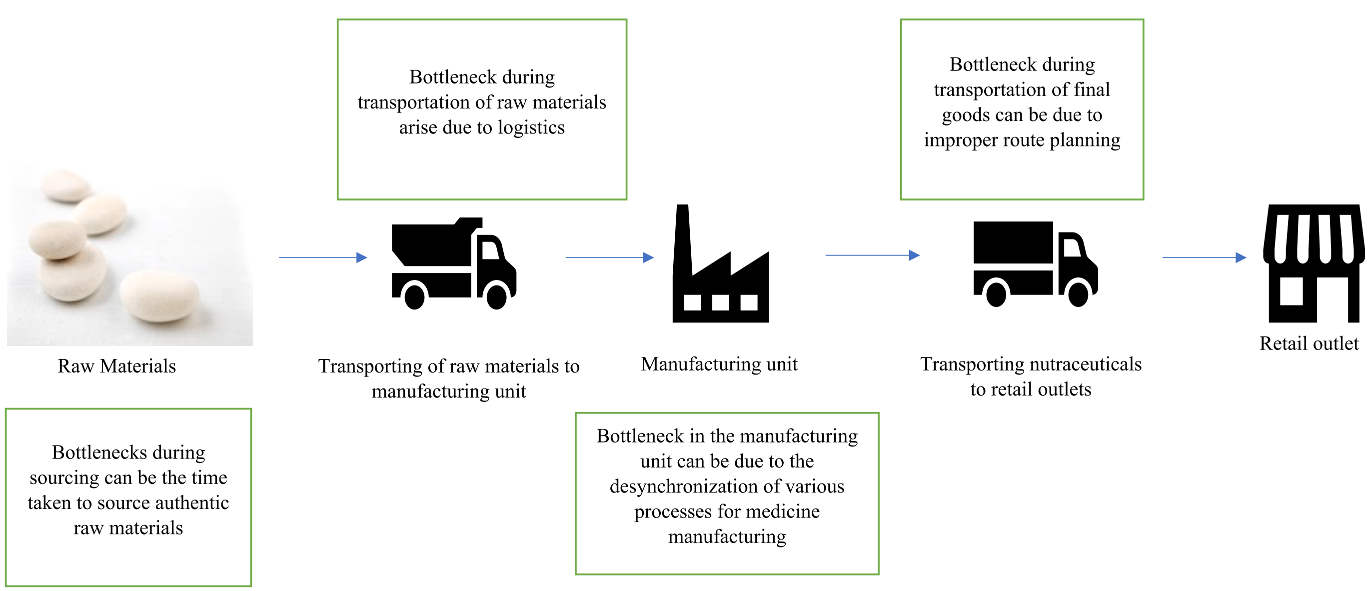

Fig. 1. Potential bottlenecks in the value-chain of nutraceutical industry.

1. Bottleneck identification- This happens during the identification process when blockchain technology is used. The system's embedded blockchain technology aids in the identification of the system's bottleneck.
2. Bottleneck addressing- When the exact location of a bottleneck is identified, the bottleneck is addressed. The data embedded in the bottleneck about the machine's current efficiency and output is decoded and compared to the designed output, and the percentage of bottleneck is determined. After identifying the bottleneck, steps are taken to alleviate it.

4.1. Case study based on realistic scenario

In this paper, we created two realistic post-pandemic case scenarios to compare whether it is more beneficial to build additional assembly lines and search for additional or alternative raw-material sources and distribution channels to meet the surge in demand for nutraceuticals in the post-pandemic era, or to implement blockchain technology to address bottlenecks and increase system efficiency.

First, we will look into the possibility of adding another assembly line, as well as alternative raw material sources for dietary supplements, as well as expanding the capacity of the existing nutraceutical distribution system to end customers. Fig. 2 depicts the increase in demand for nutraceuticals during and after a pandemic.

This paper focuses on manufacturing and distribution of vitamin E supplement, which is one of the most important components for boosting the body's immunity. This supplement is available from the pharmacist without a doctor's or other appropriate authority's prescription. The demand for medicine to boost one's immunity is increasing by the day in the post-COVID era. This sudden increase in demand for the supplement may put a strain on the existing infrastructure, creating a bottleneck that impedes the consistent supply of medicine into the market for purchase by the end consumer. Fig. 3 depicts the blockchain implementation from sourcing to final product delivery.

If pre-pandemic demand for Vitamin E tablets was around 5 million bottles, with each bottle containing 60 tablets, demand for the supplement will skyrocket to 7.5 million bottles, with each bottle containing 60 tablets, within 2 to 2.5 years of the pandemic's onset in March 2020. These supplement manufacturers lacked the time and resources to increase their manufacturing capacity.

Because the manufacturing and distribution units did not ramp up the production facility for the dietary supplement, there were bottlenecks in the supply chain from raw material sourcing to final product distribution. The active pharmaceutical ingredients, or APIs, required for the manufacture of medicine became expensive due to an unexpected increase in demand in the absence of adequate supply. The high cost of raw materials, combined with limited supply, may cause another bottleneck in the supply chain upstream.

Along with the challenges of sourcing and manufacturing dietary supplements, there is also the challenge of getting the finished product from the factory to retail stores for customer sale. The sudden surge in popularity of the supplement has put a strain on the existing distribution infrastructure for finished goods to retailers. The time it takes to deliver goods from warehouses to retail stores can create a bottleneck, impeding the delivery of dietary supplements from warehouses to retail units.

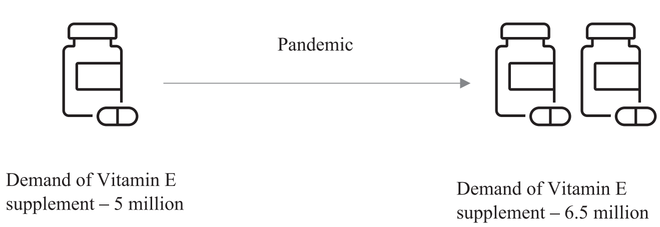

Fig. 2. Increase in demand for nutraceuticals during and after a pandemic.

4.1.1. Case I

If additional sources for raw materials for the manufacturing of nutraceuticals are identified, the procurement team will need more time and resources to finalise the contract with the suppliers so that they can get the best materials at competitive prices. The timing of the contract negotiation is not fixed and may be long or short depending on the buyer's leverage over the supplier (Klein et al. , 2003). The contract would have complicated terms and conditions because it involves the procurement of raw materials used to manufacture dietary supplements or nutraceuticals.

Identifying a potential vendor who meets all of the dietary supplement industry's criteria is thus difficult and time consuming. Furthermore, as the number of stakeholders grows, the procurement process becomes more complex (Roehrich & Lewis, 2014). The increased complexity caused by the increase in stakeholders would result in an increase in time spent formulating the contract, potentially putting the organisation at a competitive disadvantage in comparison to its competitors. The figure below depicts the enhancement of infrastructure of the value-chain to cater to increase in demand of nutraceuticals.

To meet the increased demand, the number of suppliers for raw materials or APIs used in the manufacturing of dietary supplements has increased. The production facility must also be expanded, which will necessitate additional capital investment. Furthermore, additional infrastructure for the distribution of dietary supplements is required in order to distribute the additional amount of nutraceuticals, which would necessitate additional capital investment. The company can raise the price of the supplements to recoup the capital. However, it is possible that by raising the price of the supplements, it will lose market share to competitors selling the product at a lower price.

Furthermore, once the infrastructure for sourcing raw materials, assembly lines for supplement manufacturing and packaging, and additional resources for final product delivery are in place, it will be difficult to recover the capital expenditure that occurred at three levels, beginning with the sourcing of raw materials, manufacturing of nutraceuticals, and delivery of finished product to the end custodian. Contract cancellation with API suppliers and renegotiating with delivery partners due to a drop in demand would be particularly difficult.

Contract cancellations at the sourcing and distribution levels may cause vendors to feel betrayed, leading to disengagement and the eventual collapse of the supply chain network (Liu et al., 2012).

4.1.2. Case II

As previously proposed in the paper, we intend to use blockchain technology to address and solve the bottleneck problem. If pre-pandemic demand for Vitamin E tablets was around 5 million bottles, with each bottle containing 60 tablets, demand for the supplement will skyrocket to 6.5 million bottles, with each bottle containing 60 tablets, within 2 to 2.5 years of the pandemic's onset in March 2020. These supplement manufacturers lacked the time and resources to increase their manufacturing capacity.

We can obtain high-quality ingredients by utilising blockchain technology to source APIs from their source, which also ensures a consistent supply of APIs. The technology would ensure the security of information generated while sourcing raw materials, adding an extra layer of security to the quality and authenticity of the raw materials. Blockchain technology would allow us to ensure a consistent supply of raw materials by analysing information on the quantity of raw materials required and the time it takes to be delivered from the source to the factories. The blockchain technology would also investigate how much time and resources, such as electricity and raw materials, the manufacturing unit would require to process the APIs into its final product. The data can be interpreted to calculate the resources required to produce one unit of the dietary supplement. The figure below depicts the utilizing blockchain technology to optimize the existing resources of

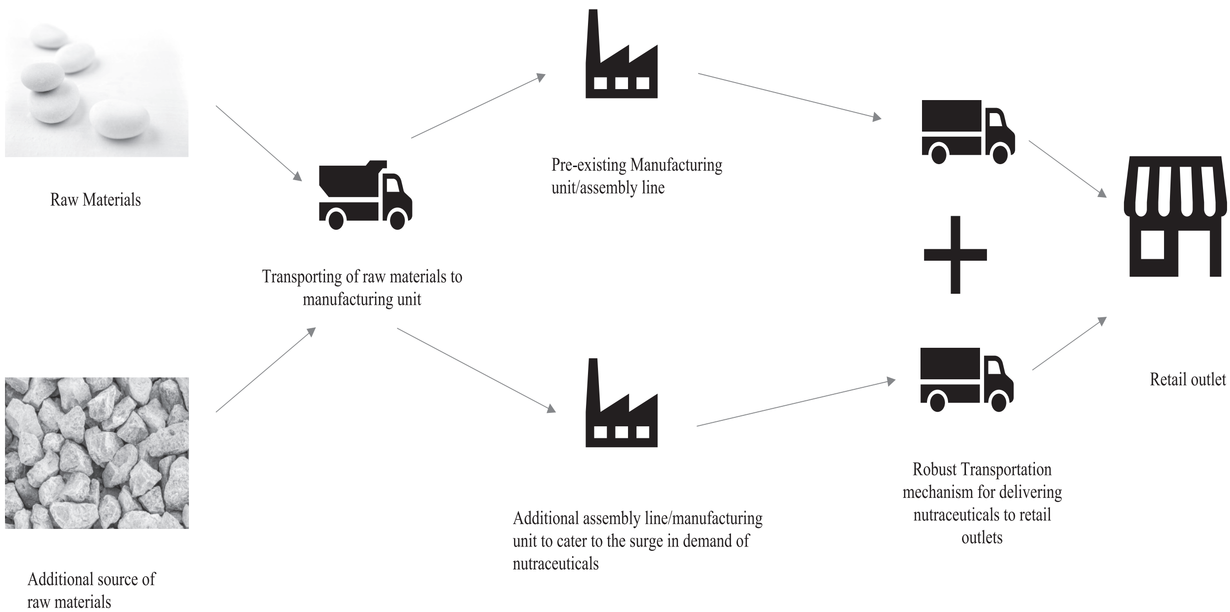

Fig. 3. Enhancement of infrastructure of the value-chain to cater to increase in demand of nutraceuticals.

the value chain.

The data obtained for the production of one unit of the dietary supplement allows us to investigate how resource utilisation can be improved and the supplement manufactured with fewer resources. Bottlenecks in the manufacturing unit would be eliminated if dietary supplement manufacturing resources were optimised. Blockchain technology can be used to track the time it takes for a product to be delivered from the warehouse to the customer. Delivery optimization in terms of less time would ensure the most efficient use of existing resources and the timely delivery of a large number of goods. Fig. 4 depicts the addition of an assembly line to meet the increased demand for nutraceuticals.

When the two cases mentioned above are compared, increasing the manufacturing capacity of the plant would necessitate capital investment. The company can raise the price of the supplements to recoup the capital. Because the price of the manufacturer's supplements is less than the price of the manufacturer's supplements, the price increase may cause the company to lose market share. Furthermore, if dietary supplement demand falls, the infrastructure and assembly line for supplement manufacturing and packaging will be idle.

As a result, investing in a second assembly line is a bad idea if demand for supplements falls. Blockchain technology can be used to avoid the capital investment required to build a new assembly line while also speeding up the manufacturing process. Purchasing blockchain technology is less expensive than purchasing a manufacturing line. Also. The technology can be tailored to meet the market's changing needs. Initially, it can be used to track, monitor, and address bottlenecks in its sourcing, manufacturing, and distribution of finished goods to final customers. Later on, as demand stabilises and the manufacturer is able to address bottlenecks while also making the system agile enough to respond to market demand changes in a short period of time, the system becomes extremely agile. This allows the focus to be on the manufacturing of dietary supplements rather than how to safely and securely store raw materials and finished goods without compromising the quality or shelf life of the raw materials.

Although blockchain technology requires an initial investment, it saves money in the long run by optimising resources and lowering fixed and variable costs in the manufacturing of dietary supplements (Yoon

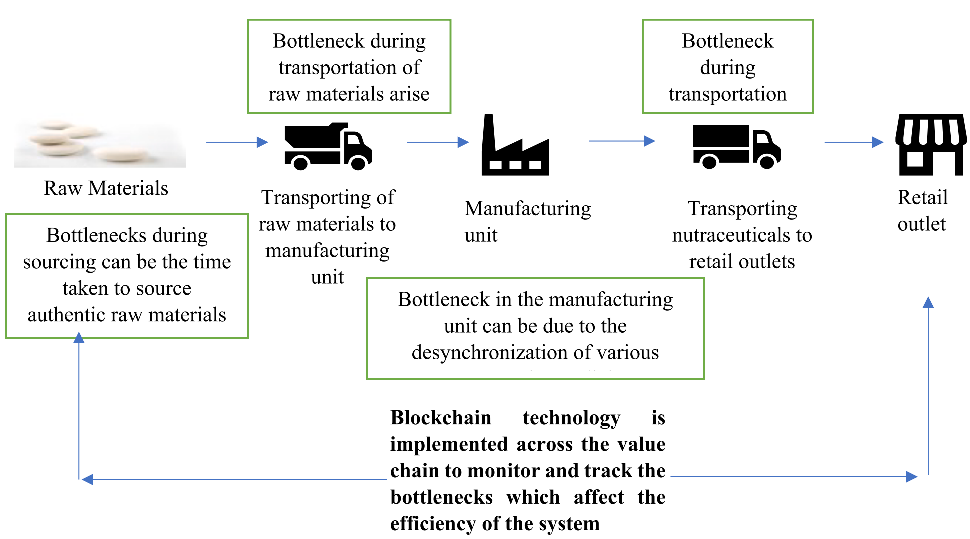

Fig. 4. Utilizing blockchain technology to optimize the existing resources of the value chain.

et al., 2020). The implementation of technology for optimising nutraceutical production would also result in the development of proprietary technology, which could provide a competitive advantage to the organisation that is implementing the technology as part of its end-to-end solution to optimise existing resources and increase efficiency.

5. Solution approach

The Fig. 5 depicts the solution for implementing blockchain technology along the value chain of the nutraceutical industry. The diagram is divided into five steps, beginning with the procurement of raw materials and ending with the distribution of nutraceuticals to retail outlets for sale to end users. The paper suggests two approaches to addressing bottlenecks in raw material sourcing, nutraceutical manufacturing, and finished goods distribution to end users (see Fig. 6).

To record and analyse information about raw material sourcing, nutraceutical manufacturing, and finished goods delivery to end customers using blockchain technology. The blockchain technology will store information in an encrypted format that only those with permission to access and analyse the data will be able to access. Due to the decentralised nature of blockchain technology, users would be able to remotely access, monitor, and analyse data. Following the analysis, the team would determine whether a bottleneck exists. If there is a bottleneck, the team will devise a solution to address it.

Fig. 5 depicts the use of blockchain technology throughout the value chain of the nutraceutical industry, which would record information about the sourcing, manufacturing, and distribution of finished goods to retail outlets in an encrypted format that a group of authorised personnel could access remotely. The data can be analysed and interpreted to determine if the actual output is less than the designed output at any stage, indicating the presence of a bottleneck. The figure below summarizes how blockchain can be used to record, store, and analyse data.

5.1. *Mathematical model formulation*

The mathematical model's primary goal is to conduct a comparative analysis to determine which of the following approaches to addressing the bottleneck is the most effective:

- Adding an assembly line or manufacturing capacity for nutraceutical production.
- Using blockchain technology to optimise resources and increase the efficiency of existing infrastructure while avoiding the addition of new infrastructure.

As a result, we must minimise two variables in the mathematical model:

1. Time required to implement either of the two methods to increase capacity so that the system can accommodate increased demand.
2. Capital is required for either of the two systems to be implemented.

Description:

Here the mathematical model which highlights the difference between application blockchain technology and enhancing the infrastructure across the value-chain of the nutraceuticals from the sourcing of raw materials to the manufacturing of nutraceuticals to the

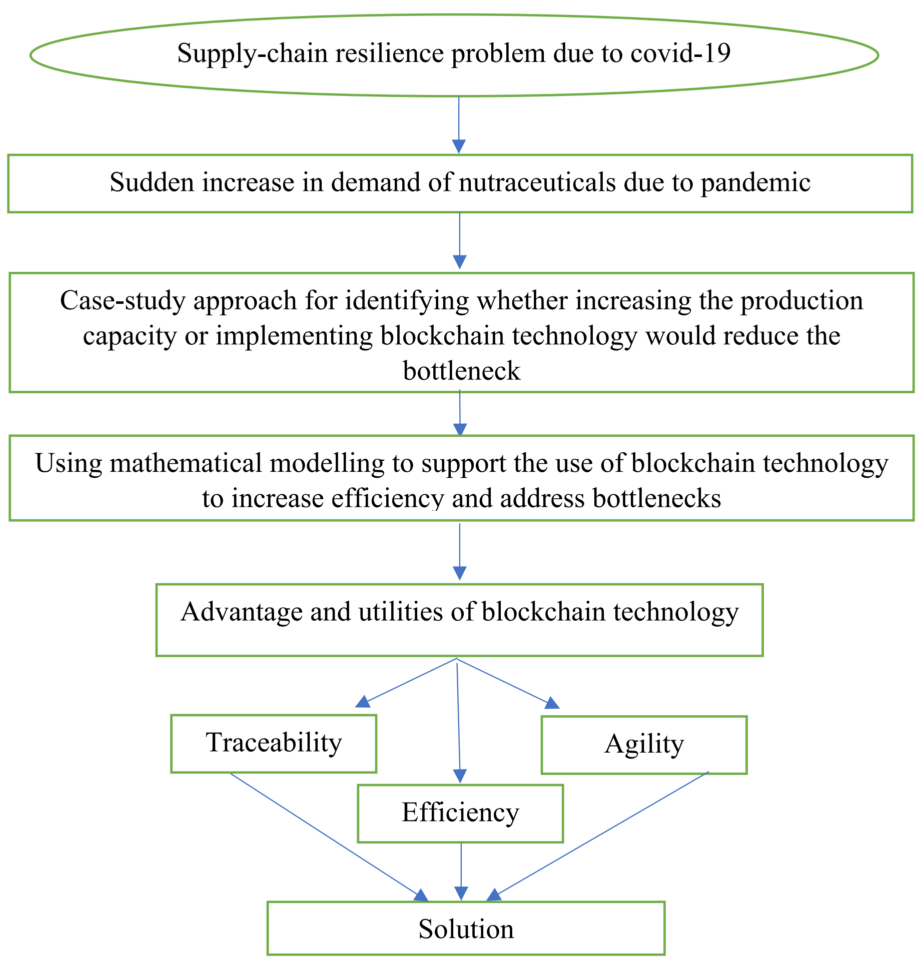

Fig. 5. Solution approach.

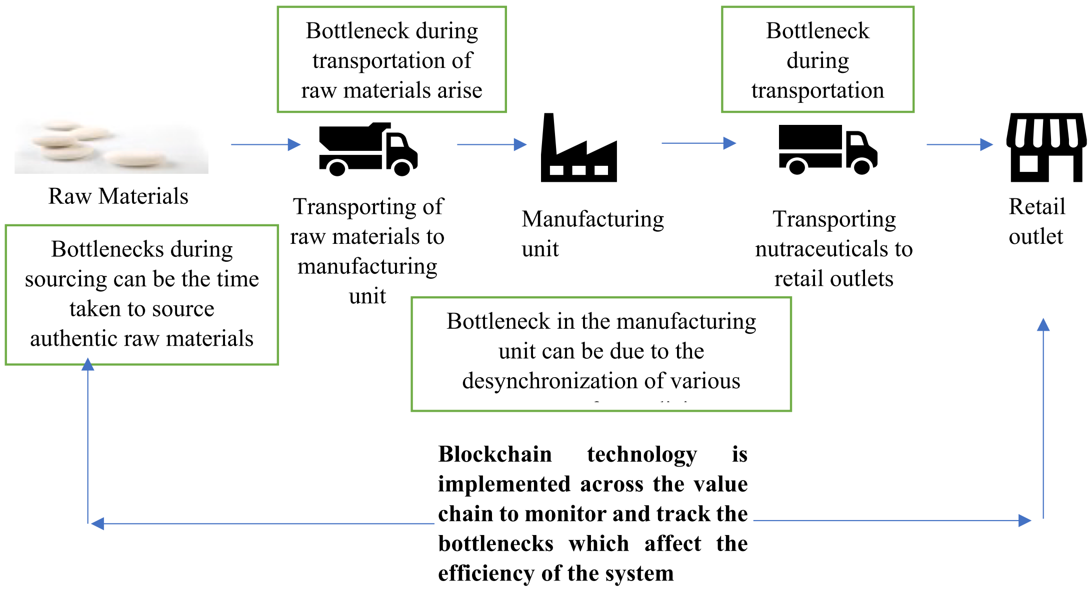

Fig. 6. The use of blockchain to record, store, and analyse information.

distribution of final product to the end consumers. The table below lists of variables and their respective unit of measurement. Similarly the Table 2. summarizes of values which have been taken to support the utility of blockchain technology.

Therefore,

$B_s.S < 1$, considering the bottleneck is hindering the efficiency in terms of time and resources used for sourcing the raw material used to make the nutraceuticals. So, when the bottleneck is factored into the system the overall output becomes less than ideal.

Similarly, for the manufacturing of nutraceuticals, the outcome after factoring the bottleneck becomes.

Table 2
List of variables and their respective unit of measurement.

Variable	Details	Unit of measurement
B_{so}	Blockchain technology used while sourcing of raw materials for the manufacturing of nutraceuticals.	NA
B_{ma}	Blockchain technology used while manufacturing of nutraceuticals	NA
B_{di}	Blockchain technology used while distributing the finished nutraceuticals to the consumers.	NA
S	Source of raw materials for the manufacturing of nutraceuticals	T(ton)
M	Manufacturing process of nutraceuticals	T/hr (ton/hour)
D	Distribution process of nutraceuticals	T/day (ton/day)
B_s	Bottleneck at the sourcing of raw materials for the manufacturing of nutraceuticals	NA
B_m	Bottleneck at the manufacturing of nutraceuticals	NA
B_d	Bottleneck at the distribution of nutraceuticals to the final customers	NA
T	Time taken for implementing the blockchain technology across entire value chain where the technology is shared within the domain of sourcing of raw materials, manufacturing of nutraceuticals and the distribution of final product to the consumers	In hours
R	Resources used for the implementation of blockchain technology across entire value chain (resources here are considered in terms of money spent to implement the technology)	In millions (USD)
T_v	Time taken to ramp up the infrastructure of the value-chain	In hours
R_v	Resources used for enhancing the infrastructure (resources here are considered in terms of money spent to implement the technology)	In millions (USD)

$B_m.M < 1$

For the distribution of the finished nutraceuticals, the outcome after factoring the bottleneck becomes,

$B_d.D < 1$

Let T be time taken for implementing the blockchain technology and R be the resources used for the implementation of blockchain technology across entire value chain where the technology is shared within the domain of sourcing of raw materials, manufacturing of nutraceuticals and the distribution of final product to the consumers.

We are assuming that post the implementation of blockchain technology the system is becoming efficient and is surpassing the designed output.

T + R would result in the fractional increase in the output post the implementation of blockchain technology which is referred to as F.

So, for the final out post the implementation of blockchain technology the efficiency at the source becomes,

$F_s *S > 1$ being the designed output in absence of bottleneck.

In the manufacturing process post the implementation of blockchain technology the efficiency becomes.

$F_m*M > 1$

And for the distribution of final product the distribution process posts the implementation of blockchain technology becomes

$F_d*D > 1$

Where F_s, F_m and F_d is the fractional increase in the overall efficiency post the implementation of blockchain technology at the sourcing of raw materials, manufacturing of nutraceuticals and the distribution of final product to the end customers.

For increasing the infrastructure of the overall value-chain to cater to the increase in demand in the post pandemic era, we have made certain assumptions.

1. The manufacturer of nutraceuticals has identified another supplier of raw materials.
2. The manufacturer of the nutraceutical has installed another additional assembly line for doubling the manufacturing capacity of the factory with identical process required for manufacturing without any modifications.
3. The bottlenecks in the pre-existing processes also exist in the additional installed infrastructure.
4. The time taken and the resources used to ramp up the infrastructure of the value-chain of the nutraceutical is greater than the time and

the resources used to implement blockchain technology to optimize the existing resources.

Let the time taken to ramp up the infrastructure of the value-chain be T_v and the resources used for enhancing the infrastructure be R_v.

If another source of raw material is finalized, then the final equation with regards to the efficiency becomes.

$2B_s.(T_v + R_v).S < 1$…………………(i)

In the same way, once the manufacturing unit is doubled by installing an additional assembly line, the final equation becomes,

$2B_m.(T_v + R_v).M < 1$………………..(ii)

Similarly, if we assume that distribution channel is doubled to cater to the increased demand, so the final equation becomes,

$2B_d.(T_v + R_v).D < 1$………………(iii)

Here in the above-mentioned equations (i), (ii) and (iii) we are assuming that despite the increase of infrastructure to produce greater quantity of nutraceuticals, the bottleneck still persists which reduces the overall production and distribution facility lesser than the designed capacity by 2* Bs or 1.6 times at sourcing stage, 2*B_m or 1.2 times at manufacturing stage and 2*Bd or 1 times at the distribution of finished product.

Realistic Comparison between whether to increase the capacity of the value-chain for the manufacturing of nutraceuticals or to implement blockchain technology to optimize the existing infrastructure of the manufacturing process.

5.1.1. Case I

Using blockchain technology to mitigate the increase in demand in nutraceuticals, the increase in efficiency at the sourcing for the raw materials needed for the manufacturing of nutraceuticals becomes (T + R) or 1.5 times.

We are assuming that post the implementation of blockchain technology the efficiency increases to 1.5 times which will result in the increase of the output to 6*1.5 = 9 million tons of nutraceuticals per year. And for the manufacturing and distribution of nutraceuticals the output increases to 5*1.5 = 7.5 million bottles of nutraceuticals per year

So, we can conclude that the investment of 6 month and $1.5 billion would raise the output to 9 million ton for the sourcing of raw materials required for the manufacturing of nutraceuticals and 7.5 million bottles of nutraceuticals per year.

5.1.2. Case II

Using traditional method of enhancing the sourcing, production, and distribution capacity of the value-chain to mitigate the increase in demand in nutraceuticals. The increase in efficiency at the sourcing for the raw materials needed for the manufacturing of nutraceuticals becomes (T_v + R_v) or 1.5 times.

We are assuming that post the ramping up of the sourcing of raw materials, manufacturing facility of nutraceuticals and distribution infrastructure of nutraceuticals using $ 1.8 billion of resources and 18 months of time the efficiency increases to 1.5 times which will result in the increase of the output to 6*1.5 = 9 million tons of nutraceuticals per year. And for the manufacturing and distribution of nutraceuticals the output increases to 5*1.5 = 7.5 million bottles of nutraceuticals per year

So, we can conclude that the investment of 18 months of time and $1.8 billion of monetary resources would raise the output to 9 million ton for the sourcing of raw materials required for the manufacturing of nutraceuticals and 7.5 million bottles of nutraceuticals per year (see Tables 3 and 4).

But as per the earlier equations under the increase of the sourcing, production and distribution capacity, the bottlenecks will also increase under the assumptions which we have made earlier. Therefore, the risk of increasing the infrastructure is greater than the risk of implementing blockchain technology.

Table 3
List of values which have been taken to support the utility of blockchain technology.

Variable	Value
B_{so}	1.5
B_{ma}	1.5
B_{di}	1.5
S	6 million ton
M	5 million bottles
D	5 million bottles
B_s	0.8
B_m	0.6
B_d	0.5
T	6 months
R	$ 1.5 billion
T_v	18 months
R_v	$ 1.8 billion

Table 4
List of scenarios which shows the benefit and advantages of blockchain technology.

Scenario	Methodology	Risks involved
1. The demand of nutraceutical increases	Investing in the infrastructure to increase the production capacity	1. High capital investment 2. Increased amount of time required to build the infrastructure 3. Higher number of parties involved 4. Loss of business opportunity due to the time required to build the infrastructure 5. No surety whether the bottlenecks will decrease due to the increase in capacity 6. New and never seen before bottlenecks might come up
	Investing in blockchain technology to optimize the existing infrastructure and resources to increase productivity.	1. Thorough technical knowhow is needed to implement and run the technology 2. Workers need to be trained for working with the blockchain technology
2. The demand of the nutraceutical decreases	Investing in the infrastructure to increase the production capacity	1. The overall infrastructure will lie idle thus making the overall process inefficient and expensive 2. The value-chain will take time to adapt to the change as there will be a lot of raw materials and inventories which would be needed to be addressed on an urgent basis
	Investing in blockchain technology to optimize the existing infrastructure and resources to increase productivity.	1. The blockchain technology would be under-utilized

5.2. Failure mode and effect analysis (FMEA)

To support our case for incorporating blockchain technology into the nutraceutical value chain, we will conduct a failure mode and effect analysis (FMEA) to identify the risks of implementing the two methodologies. The FMEA methodology was used in this methodology to analyse the failure of any initiative or project and how the risks associated with each impact the overall progress of work. Stamatis (2003) describes the mechanism and workings of FMEA in detail. Fig. 7 depicts the FMEA for risk reduction, risk elimination, and risk transfer.

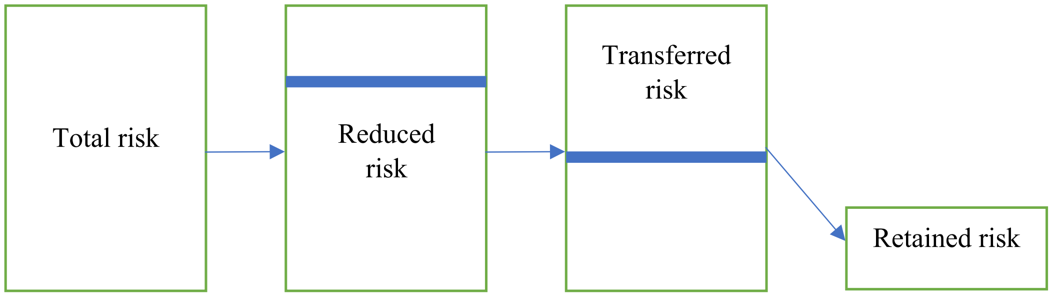

Fig. 7. FMEA for risk reduction and risk elimination and risk transfer.

According to the literature, the FMEA is based on a few assumptions, which are as follows:

1. Since no two problems are the same in terms of severity, the approach to solving them should be different.
2. The customer should be kept informed of the issue and its potential impact on the entire project. As a result, necessary steps should be taken to solve or mitigate the impact based on the impact and the timeline within which the impact will occur.
3. The project's ultimate goal should be clear. The goal and its impact on achieving long-term and short-term strategic goals should be well understood. This would provide project stakeholders with a clear picture of the project's importance and the impact of the problem, which would then be mitigated.
4. Even if a proper mitigation strategy for the problem, whether it has occurred or will occur, is planned and implemented, stakeholders should focus on avoiding the problem entirely rather than identifying mitigating strategies.

Risks associated with assembly line construction:

1. Multiple parties with varying cognitive abilities are involved.
2. A multi-step construction process with its own value chain
3. Risks such as raw material supply and labour shortages would cause construction to be delayed.
4. Chances of the assembly line becoming idle if demand falls or becomes cyclical in nature.

The aforementioned risks may cause a delay in assembly line execution, resulting in a bottleneck and reducing system efficiency. FMEA for the implementation of blockchain technology to improve system efficiency. Risks associated with implementing blockchain technology to improve value chain efficiency include:

1. Lack of efficient and skilled professionals for quick and agile blockchain technology implementation
2. Lack of skilled workers generates a block of blockchain technology if it is required for entering data related to the sourcing, production, and transportation of nutraceuticals from the origin of raw material sourcing to the delivery of final product to end customers.
3. There is a scarcity of professionals who can train factory workers to use blockchain technology.

As a result, we can see that there are risks associated with implementing blockchain technology and constructing an assembly line to improve the value chain's efficiency and the capacity of the nutraceutical assembly line. However, we can assume that a smaller number of people are involved in blockchain technology implementation, and that everyone involved has the same cognitive ability, so there will be much more coordination among the teams, increasing the overall system's efficiency (Laufer et al., 2022).

5.3. *Leveraging blockchain to improve in nutraceutical supply chain resilience*

Blockchain technology is a tamper-resistant and tamper-proof system that stores process information as well as the nuances of the data involved (Yang et al., 2020). A blockchain, according to PricewaterhouseCoopers (2022), is a "decentralised ledger" used to keep records or conduct peer-to-peer transactions in the absence of a central clearing authority. was designed to serve as a cryptocurrency support system. It is a highly sophisticated and secure method of storing information that is finding use in a wide range of domains, most notably sourcing, manufacturing, and distribution. According to Yli-Huumo et al. (2016), since its inception in 2008, there has been a steady increase in interest in blockchain and finding ways to implement it. Numerous applications have been discovered since then.

Given the characteristics of blockchain technology, specifically how it enables decentralisation, transparency, trust, anonymity, and stability, the paper proposes using blockchain technology in the nutraceutical industry as a viable way to meet demand while lowering overall production costs. Blockchains can be used to track API production, distribution, and acquisition. The use of blockchain technology improves the safety and affordability of nutraceutical manufacturing while also reducing the number of middlemen (Huang, Wu & Long, 2018). Fig. 8 depicts a flowchart of the Blockchain Technology implementation.

Blockchain technology is beneficial in a variety of ways. Blockchain, via smart contracts, has the potential to significantly improve tracking, tracing, visibility, accountability and trust, and thus have a positive impact on the operation of the nutraceutical industry (Babich & Hilary, 2020). Blockchain is a decentralised, encrypted system in which documented transactions cannot be edited or erased and the entire transactional chronology can be examined simultaneously by any authorised network participant.

The support of policymakers is critical for faster blockchain adoption. In India, the National Institute for Transforming India is working with large nutraceutical manufacturers and hospital chains to prevent counterfeiting in the nutraceutical supply chain by implementing the Oracle blockchain solution (PIB, 2018). To encourage faster adoption and thus improve the health of Indian citizens, the Indian government is subsidising implementation. Oracle Blockchain Solution offers blockchain as a service (Blockchain as a Service). Businesses can use it to run apps on immutable digital distributed ledger repositories.

According to Haq & Muselemu (2018), blockchain can be used in the nutraceutical supply chain to ensure traceability and thus avoid counterfeiting: when a drug is manufactured in the factory, the manufacturer will generate a unique hashcode and link it to the drug. This hash will be used to give the drug a unique identity on the blockchain network, allowing it to be traced. This is how the drug will appear on the network as a digital asset of the manufacturer. If the manufacturer wants to include any additional information about the product, it can be saved on the blockchain as well. Because the manufacturer has now registered the product on the blockchain, ownership can easily be transferred to another participant with the help of a simple smartphone app. The

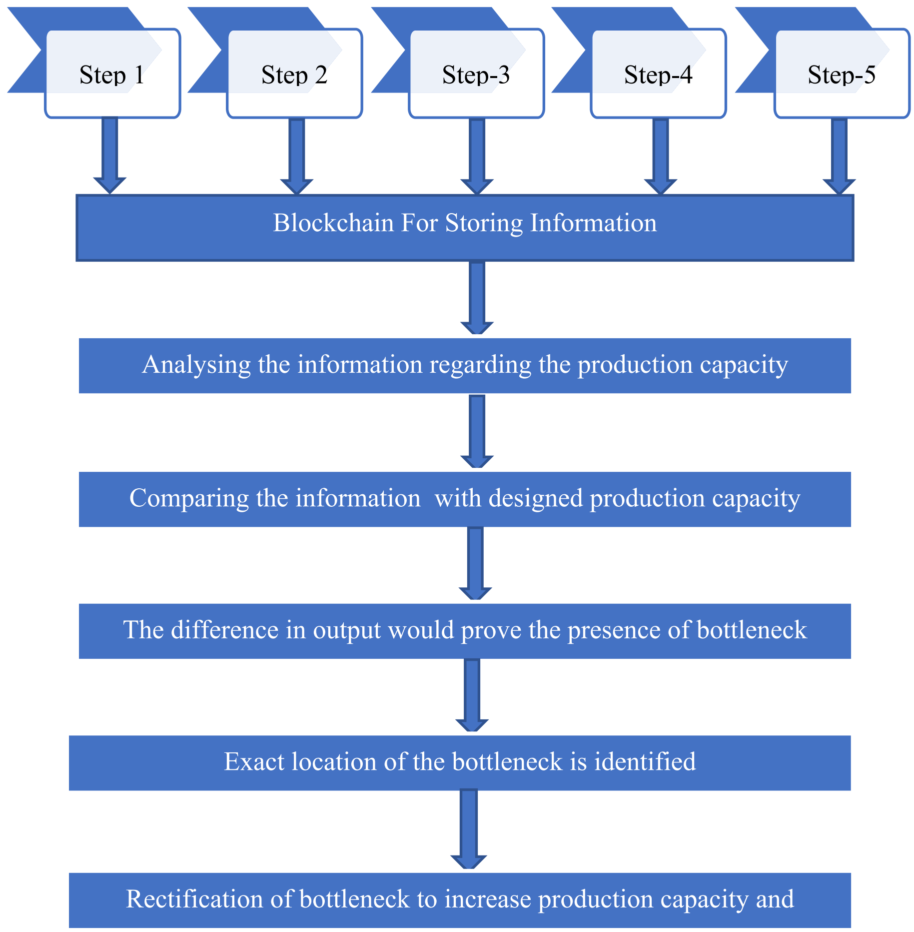

Fig. 8. Flowchart showing the implementation of Blockchain Technology.

manufacturer can deliver the drugs to the wholesaler in person while also recording the physical goods transaction on the blockchain. The wholesaler will proceed in the same manner as the manufacturer and pass the drugs on to the distributor; similarly, the distributor will proceed in the same manner as the pharmacy or retailer.

5.4. Utilities of blockchain technology in the manufacturing

In the paper, we proposed using blockchain technology to identify and mitigate bottlenecks in the sourcing, manufacturing, and distribution of nutraceuticals. This is made possible by three aspects of blockchain technology. These are their names:

1. Using blockchain technology to improve raw material traceability (Fan et al., 2022)
2. Using blockchain technology to improve production line efficiency (Zagurskiy & Titova, 2019), (Kucukaltan et al., 2022)
3. Using blockchain technology to increase the agility of distributing finished goods or nutraceuticals to the shop for delivery to end users (Francisco & Swanson, 2018)

These three components of blockchain technology can be used to make it easier to locate raw materials, manufacture nutraceuticals, and transport finished products to stores where they can be sold to end users. Fig. 9 depicts the applications of blockchain technology in the manufacture of nutraceuticals.

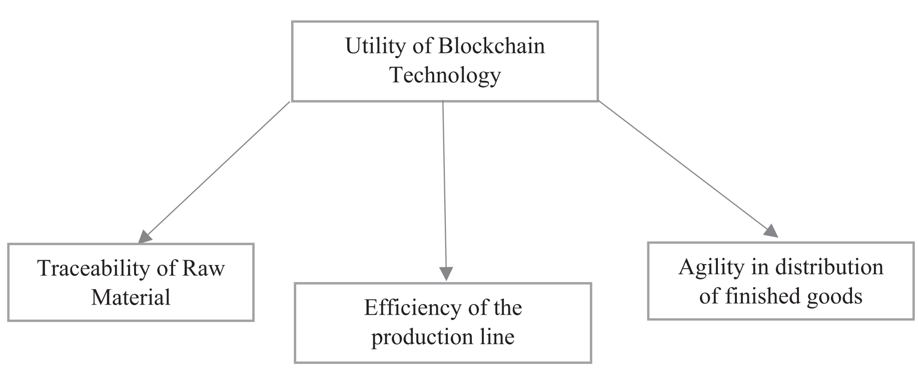

Fig. 9. Utilities of blockchain technology in production of nutraceuticals.

5.4.1. Using the blockchain technology to increase the traceability of raw materials

Several studies have been conducted to investigate raw material traceability using blockchain technology (Patelli & Mandrioli, 2020). (Collart & Canales, 2022) explains how the blockchain stores immutable and untouchable transactions. As a result, with each transaction, the blockchain expands and risks becoming “bulky.” In a permissionless system, where each block must retain every previous transaction and can be accessed by an arbitrary number of users, this is a problem. In the case of a food traceability system with a small user base, this limitation is less significant.

The commercial adoption of BCT in the supply chain requires sensitive information protection and, in some cases, user anonymity. For example, scenarios in which only a few users of a blockchain should be known to all users could be established. Furthermore, in order to facilitate effective trading, specific information in the blockchain may need to be protected from unauthorised access and leakage. Despite the fact that the original blockchain design provided little functionality for securing sensitive data, current commercial platforms have recognised this need and provide the ability to control access to information on the blockchain.

The use of programming languages, as well as proper technological implementation, are required for blockchain technology. Such software is vulnerable to poorly written or maintained code, allowing financially motivated hackers to exploit such flaws. The security of blockchain implementations will be critical for the widespread adoption of BCT in the supply chain domain due to the processing of sensitive data during the supply chain process.

The blockchain stores transactions that cannot be changed or touched. As a result, with each transaction, the blockchain expands and risks becoming “bulky.” In a permissionless system, where each block must retain every previous transaction and can be accessed by an arbitrary number of users, this is a problem. This is less of an issue for a food traceability system with a small user base. For the commercial use of blockchain technology in the supply chain, the amount of sensitive information protection and, in some cases, the level of user anonymity protection are required. For example, scenarios in which only a few users of a blockchain should be known to all users could be established.

Furthermore, some blockchain information may need to be proprietary in order to enable effective traceability, necessitating protection against unauthorised access and leaks. Despite the fact that the original blockchain design provided little functionality for securing sensitive data, current commercial platforms have recognised this need and made it possible to limit access to information on the blockchain.

5.4.1.1. The traceability factor work in four ways. **Data layer**- Enough data on demand fluctuation, seasonality of raw material demand, and raw material quality has been accumulated over time. The data layer serves as the architecture’s foundation. Data storage during the registration process is critical for ensuring traceability’s viability and efficacy later on. A single data layer block is a grouping of transactional data that includes registration information. Each block has its own hash value. The preceding block’s hash value connects the following block in a chain structure, allowing for the sequential storage of transaction data. The following related block can be used to trace the path of all information in each block. Each block contains data from the original accomplishments, ranging from the registration activity to the associated transactional actions. All transactional data is meticulously tracked and saved in blocks that are highly traceable.

Contract layer- The contract layer allows for the deployment of blockchain smart contracts. It serves as the foundation for the architecture of the traceability service. The main components of this layer are the script code design, the operation of the algorithm mechanism, and the smart contract code design. The use of smart contracts in the traceability service architecture has the advantage of automatically executing smart contracts if specific conditional code is placed in them. That is, as long as a smart contract is pre-coded in the contract layer, the initial achievement’s traceability can be enabled automatically. “Automation” in the context of blockchain refers to the enforcement of all contract conditions in accordance with laws and the function’s validity without the use of intermediaries. We primarily use smart contracts in this layer’s reward mechanism to track down and automatically reward original accomplishment producers.

Logical layer- A logical embodiment connects blockchain technology to the original achievement mechanism via the logical layer. It exists in the space between data transformation and data abstraction. It is the logical basis for the entire service architecture. The logic layer connects the blockchain’s consensus algorithm and the criteria for intelligent contracts to the business logic of the original achievements. By receiving user commands or data input, transferring it to the data layer for processing, and then displaying the results back to the end users, it creates a feedback loop between user interfaces and data management. In this layer’s reward system, smart contracts are heavily used to locate and automatically reward creators of original accomplishments.

Application layer- The proposed service architecture’s application layer primarily entails the implementation of original achievement protection based on the blockchain. The main activities at this tier are achievement registration, confirmation, trading, and rewarding. Furthermore, customization can be done for a variety of businesses, groups, and individuals. The application layer—the user application interface—of this novel achievement traceability service architecture allows end users to submit customised needs.

Blockchain technology necessitates the development of an architecture that supports multiple supply chain processes and allows actors to play multiple roles. A provider does not want to deal with various blockchain architectures from various clients. This would result in significant fragmentation and complexity in how the various blockchains interact with one another. Standardization in the direction of a blockchain platform is required to accommodate various consortium supply chain activities. Appropriate data should be gathered in order to track down the source of the raw material.

5.4.2. Using the blockchain technology to increase the efficiency of the production line

According to Gurtu & Johny (2019), extensive research has been conducted on the use of blockchain technology to improve manufacturing and supply chain efficiency for a wide range of products, including nutraceuticals. This concept makes use of permissioned blockchains. It is only maintained by a network of nodes belonging to the actors in the supply chain. Each network node has equal control over the blockchain network. In order to decide whether or not to admit a new node (an aspirant) to the network and reach an agreement, all nodes must be aware of the node’s identification and how it participates in the supply chain process. Participants should agree to reject an aspirant’s admission if their identity is unknown, such as when they are an attacker seeking network control or an actor seeking to increase their control over the blockchain, in order to maintain the blockchain’s current state of shared control. Clients who purchase finished goods but do not participate in the supply chain can request permission from nodes to read from the blockchain but not write to it.

The blockchain technology stores information about nutraceutical production. They save real-time data on how many medicines were manufactured in a given time period. Seasonality and market trends can cause fluctuations. To determine the boundary conditions, these variations were pre-analyzed and entered into the blockchain. Any non-predefined variation in production is attributed to the presence of bottlenecks that must be addressed. As previously stated, these bottlenecks reduce the production system’s efficiency. As a result, the authority is presented with two options for increasing production capacity.

The first option is to build another assembly line. To increase production capacity, the company that manufactures nutraceuticals for market sale plans to build an additional assembly line. Increasing the plant's manufacturing capacity, on the other hand, would necessitate capital investment. To recoup the capital, the company can raise the price of the supplements. Because the price of the manufacturer's supplements is less than the price of the manufacturer's supplements, the company may lose market share as a result of the price increase. Furthermore, once the infrastructure and assembly line for supplement manufacturing and packaging are built, they will be idle if dietary supplement demand falls.

The second option is to implement or introduce blockchain technology to identify and address bottlenecks in the manufacturing facility, because investing in an additional assembly line is not a good idea if demand for supplements falls. Blockchain technology can be used to avoid the capital investment required to build another assembly line and to accelerate the manufacturing process. Investing in blockchain technology is less expensive than investing in a manufacturing line. Also. The technology can be tailored to meet the changing needs of the market. It can be used to track, monitor, and address bottlenecks in its sourcing, manufacturing, and distribution of finished goods to its final customers at first.

Later on, as demand stabilises and the manufacturer is able to address bottlenecks while also making the system agile enough to respond to changes in market demand in a short period of time, the system becomes extremely agile. This can be done to keep raw materials and finished goods to a minimum, allowing the focus to be on the manufacturing of dietary supplements rather than how to safely and securely store raw materials and finished goods without compromising the quality or shelf life of the raw materials.

Although blockchain technology requires an initial investment, it saves money in the long run by optimising resources and lowering fixed and variable costs for dietary supplement manufacturing.

There may be times when the new dietary supplement assembly line is not fully built or is operating at a lower capacity than intended. As a result, the assembly line will not be used to its full potential, eventually becoming the system's bottleneck. Blockchain technology can be used on a trial basis to alleviate such a temporary bottleneck until the assembly line is completed. The technology can be used to track the resources used in supplement manufacturing, and by analysing the data, it is possible to understand how raw materials can be sourced in a sustainable way while lowering input costs.

Blockchain technology can be used to reduce input costs for the manufacturing of dietary supplements because the manufacturer has already invested money in building the assembly line. As a result, if the company invests significantly more money in permanently implementing blockchain technology, it will incur additional costs for both blockchain technology implementation and assembly line construction. As a result, for the time being, blockchain technology can be used to provide temporary relief in supplement manufacturing and meeting the unexpected surge in demand in the post-Covid era.

The blockchain technology would enable continuous recording of production-related data, which could then be analysed to determine which step of the manufacturing process takes the longest. If that process takes longer than the time allotted.

5.4.3. Using the blockchain technology to increase the agility for distribution

Since, information cannot be changed once it has been recorded, blockchain technology can compare incoming data with external data for verification and thus authentication, addressing trust issues in commerce. The ability of the blockchain to carry out specific transactions automatically based on predefined parameters is referred to as automation. As a result, blockchain technology is being used to eliminate middlemen and regulators. Consumers may be able to obtain more detailed data as a result of blockchain technology. Consumer-choice models now only consider a few product-descriptor variables (a good dimension for analytical outcomes is "quality"), but each product has a complicated and multifaceted history. Consider a simple mango purchase. Mangoes are currently selected from stores based on simple information such as the fruit's appearance, aroma, organic label, and price. Consider what customers would learn if they could learn about the origins of each mango container, the fertilisers and pesticides used, the weather throughout the growing season, the labour methods used, the amount of time the container spent on the ship or in port, and so on.

Blockchain technology provides a platform for combining data from multiple sources over time without requiring a single centralised authority to oversee the process (firms in a supply chain, regulators, and consumers). Smart contracts have the potential to shorten lead times, automate actions based on aggregate data, and create markets for non-traditional resource trading. This allows consumers to consider the product's history when making B2C purchases. In a B2B setting, a blockchain creates a verified record of previous transactions that can be used by buyers to select suppliers or by suppliers to indicate their level of quality to customers. A blockchain can combine data from various smart sensors, share it with decision-makers, and even execute contracts autonomously in B2T and T2T transactions. The aforementioned mango pilot, for example, demonstrated that mangoes travel three days from the customs broker to a processor. If Walmart could shorten this time, the product's shelf life would be extended by one or more days, ensuring that consumers receive fresher food and reducing food waste (McKenzie et al., 2018).

A blockchain platform can be used to connect the entire supply chain, providing businesses with greater insight into the layout of their extended supply chains, allowing them to locate factories, identify potential bottlenecks, and identify excessive regional concentrations of production resources. In reality, many existing blockchain applications seek to validate product origin. Tracking the movement of goods through supply networks is one of them. This is critical for detecting risks, calculating the likelihood of negative outcomes, and forecasting their consequences. To assess the effects of a disruption, data on backup capacity and raw material stockpiles from various points along the supply chain can be collected. Businesses can develop mitigation plans and take action to prevent and mitigate supply disruptions as a result of this forewarning.

Tracking a product's chain of custody may result in a warning when unapproved sources are used. After receiving a notice, potentially faulty goods can be examined and removed from the hands of customers and later stages of production. In the case of Menu Foods, having this capability would have been advantageous. Knowing the chain of custody can help a company triangulate the source of a problem (to a specific supplier, factory, or workstation, depending on the resolution capability of the blockchain identity information). Blockchain can also be used to distinguish between clients who are and are not affected by problems.

A smart contract function can be used to send out notifications automatically. By tracking their origin, blockchain technology promises to confirm that products were produced in facilities that have been approved for conducting business in an ethical or environmentally responsible manner. Although regulatory bodies (NGOs, governments, and industry self-regulators) are required to provide certifications and conduct inspections, once certifications are stored in the blockchain system, they are unchangeable and publicly accessible if ledgers are open to the public.

6. Discussion

The paper emphasises the benefits of blockchain technology in the sourcing, manufacturing, and distribution of nutraceuticals. Before proposing a method for implementing the technology and integrating it with existing processes, the paper first conducts a comparative study to determine whether to implement blockchain technology while optimising existing resources or to install a new assembly line and other supporting infrastructures. Following a comparative analysis, it was determined that implementing blockchain technology would benefit the value chain of the nutraceutical industry in both the short and long term.

The nutraceutical industry is involved in a wide range of complex processes, from drug discovery to pharmaceutical formulation development. Following that, manufacturing with the proper ingredients in the proper dosage is performed to ensure quality control. Finally, these medications are given to patients on prescription or for self-administration of over-the-counter medications. The entire supply chain is governed by a slew of laws and regulations that govern drug patenting, testing, safety, and efficacy (Saindane et al., 2020). Despite being heavily regulated, the nutraceutical supply chain is beset by two interconnected problems: the presence of the grey market and counterfeiting.

According to (Pun et al., 2021), counterfeiting can occur in two ways:

- Non-Deceptive Counterfeiting: when patients can distinguish between a genuine and a counterfeit drug but choose to purchase the counterfeit product. This is a common practise when it comes to expensive medications. because fake drugs resemble genuine drugs but are less effective. Even so, people may buy the fake one due to cost and the perception that having the counterfeit drug is preferable to not having any treatment at all.
- Deceptive counterfeiting: occurs when a patient is unable to distinguish between a genuine and a counterfeit drug. These drugs may contain incorrect constituents and dosages, or they may be completely devoid of API. As a result, patients unknowingly take medication that does not work as it should. The risk of deceptive counterfeit drugs is not limited to the inability to treat the patient; such drugs may also cause other serious diseases or, in the worst-case scenario, death. Counterfeit nutraceuticals infiltrate the supply chain, causing havoc in the nutraceutical industry (Bocek et al., 2017).

As a result, patients and dispensaries are concerned about the authenticity of the drugs supplied. To address these issues, companies, according to Davison (2011), use sophisticated labelling techniques (e.g., holograms) that patients can easily determine the authenticity of the same. Counterfeiters, on the other hand, can easily imitate such labels but not holograms or the actual trademark. Various methods are used to track product movement as it moves downstream and changes hands, but a central unit is still involved, which could be hacked, and documentation is easily forged. A centralised repository is also vulnerable to system failures.

Blockchain technology can be one of the solutions for preventing data breaches by preventing the forging of fake information and strengthening data security. Customers' trust implies that the company that sources raw materials using blockchain technology will gain a competitive advantage. They would be able to track and provide information on the raw material suppliers. So, if a nutraceutical company claims that it sources its raw materials "ethically" or is "vegan," it may use blockchain technology to store raw material sourcing data and display it on packaging.

The information about the source of raw materials on packaging would allow the company to use blockchain technology to back up its claim, giving it a competitive advantage over its competitors. Manufacturers would also be able to record the time it takes to process raw materials into finished products and send them to retail outlets for sale to final customers using the technology. Because of this agility, the product reaches customers as soon as possible, giving them more time to consume the dietary supplements before they expire and lose their intended effectiveness.

The paper describes how blockchain technology can be used to increase production efficiency and address bottlenecks that limit nutraceutical capacity. Blockchain technology is widely used in smart contracts and data storage. It can be used to boost system security by securely storing data. This data can be analysed later to determine where the abnormal delay occurred in the sourcing, manufacturing, or distribution processes.

The new technology would be implemented in accordance with Industry 4.0 implementation across the value chain, with the primary goal of introducing connected systems and information sharing. The use of blockchain technology would enable the permissioned sharing of information among authorised personnel, who would then be able to analyse it and decide what to do if the system encountered a bottleneck. Incorporating cutting-edge technology into existing processes would enable continuous monitoring, with any impending bottlenecks addressed even before they occurred. The technology would improve the agility, efficiency, and traceability of raw materials.

Traceability refers to the ability to trace raw materials back to their source or origin. This method of tracing the origin of raw materials ensures that the raw materials sourced are of the highest quality and that the promise made to customers of producing high-quality dietary supplements with high-quality raw materials is kept. Implementing blockchain technology and mentioning it as part of the packaging would allow the organisation implementing it to gain a competitive advantage and stand out in a crowd of competitors as mentioned earlier. Customers' trust in that particular brand would increase as a result of blockchain technology's traceability. Customers would be able to verify the source and authenticity of the raw materials used in the manufacturing of the dietary supplements if the brand provided information about the source of raw materials via QR code or other means.

Following the traceability factor, which is used to verify the source of raw materials used in the manufacturing of nutraceuticals, blockchain technology can be used in the manufacturing process to increase efficiency through data storage and analysis. assuming that the manufacturing process for nutraceuticals consists of several steps If the raw materials are fed to the input at an optimum or recommended speed, these steps have a recommended output per unit time. However, if the output is less than the optimum or recommended output due to the presence of bottlenecks, blockchain technology would allow the detection and elimination of bottlenecks by continuously recording data regarding the procurement, manufacturing, and distribution of final goods, which can be compared with the originally designed production capacity and the current production capacity. This comparison would allow for determining the extent to which a lag exists (if any) and, if so, where it exists, because if there is a lag in the output at one specific location, it can be concluded that the location with the lower output contains the bottleneck, which is then identified and rectified.

Following the benefits of increased efficiency and traceability, the next advantage of implementing blockchain technology is agility. This factor aids in determining the simplest and shortest route for transferring finished goods from storage units containing batches of finished goods to retail outlets. Blockchain technology would enable the storage of information pertaining to the transportation of finished goods from the warehouse to retail outlets. The transportation delay, if any, can be identified and corrected after the information about the transportation is analysed. During the transportation of nutraceuticals from the warehouse to retail outlets, there may be delays due to various avoidable or unavoidable circumstances, which will be properly documented using technology and later analysed to determine whether any of the delays can be avoided by changing the route for transportation. The technology would enable the authority to be more agile and make faster decisions about whether to change the existing route to a newer and shorter one. The technology would enable quick decision-making regarding a route change.

The benefits of utilising blockchain technology in optimising existing resources can be implemented in raw material sourcing, manufacturing, and distribution of finished goods in the end-to-end manufacturing of any tangible product. However, the implementation of blockchain technology is most relevant and critical in the manufacturing of nutraceuticals. The nutraceuticals or dietary supplements are directly related or linked to the customer's health because the user consumes the dietary supplements to improve his or her health and avoid fatigue while performing day-to-day activities. Customers frequently consume supplements based on the brand name or market reputation of the companies that manufacture the nutraceuticals.

As a result, implementing blockchain technology would add an extra layer of security in terms of the quality of the materials sourced, the processes used for manufacturing, and the distribution of nutraceuticals. Customers can buy supplements from companies that use technology and be confident that they will receive what the company promises to give. When customers' peace of mind is converted into customer satisfaction, the company may gain market share through positive word of mouth from satisfied customers, thus fulfilling the company's ulterior motive of gaining market share and increasing profitability.

The blockchain can also be used to eliminate the risk of drug counterfeiting if any individual or group of individuals violated the formulation or intellectual property rights. The technology would assist the nutraceutical industry in resolving any given problem. The blockchain could function as a parallel and dynamic system to track the end-to-end functioning of the nutraceutical industry and, as a result, suggest ways to improve operational efficiency and efficiently conduct their research and development of new medicines or newer varieties of their existing medicine for treating the newer varieties of diseases that are evolving due to changes in weather conditions that promote disease-spreading viruses to proliferate. These viruses cause diseases with newer symptoms, and older versions of the drugs are ineffective at stopping the virus's spread.

As a result, ongoing research and development is required to treat new diseases or improved versions of existing diseases. Because of the decentralised nature of the blockchain, information can be accessed from anywhere without going through the main storage system. The data is encrypted and encoded, making it extremely secure and impenetrable. If anyone tries to tamper with the data, it records evidence of tampering and is a criminal offence. The authorised users of the system will be notified that the data has been tampered with, and they may be able to take legal action against the person or authority who committed the tampering.

Because blockchain is a new technology, its applications, particularly in manufacturing, are still being explored. Like any new technology, the implementation of blockchain technology in manufacturing would necessitate a clear strategy. Before deciding to implement blockchain technology in the manufacturing process of the nutraceutical industry, the barriers to implementation and benefits of implementing blockchain technology must be determined. Before incurring the expense of implementing blockchain technology in the dietary supplement sector, the cost of implementation, as well as the tangible and intangible benefits of blockchain technology implementation in the short and long term, should be calculated.

So, by implementing blockchain technology, the organisation would gain three major benefits: improved traceability of raw materials, increased efficiency of production processes, and increased agility in transferring goods from warehouses to retail outlets for sale to final customers.

7. Managerial implication

The paper examines how blockchain technology can be used to improve the efficiency of manufacturing and supply chain mechanisms. When compared to the manufacturing process of nutraceuticals and other dietary supplements, this is a relatively new concept. As a result, combining new and proven technology would increase the overall efficiency of the sourcing, manufacturing, and distribution processes.

Even though blockchain technology would improve the efficiency of nutraceutical sourcing, manufacturing, and distribution, any managers or organisations planning to implement it must first learn about it before incorporating it into their processes. The technology is relatively new, and it would take multiple sessions for managers to learn and acquire the necessary skillsets to upload information into the blockchain and then retrieve it for later analysis. However, the managers would also need to train the supervisors who work in the nutraceutical manufacturing unit.

However, in addition to the person working in the manufacturing unit for the production of nutraceuticals, knowledge of the technology and how to use the blockchain technology to enter information should be taught to the personnel in charge of sourcing raw materials and the delivery team for delivering the dietary supplements to the final customers. These people should be taught how to create blockchain blocks and enter data that will later be analysed.

Employees may object because they are hesitant to learn new technology, but they should be taught about the long- and short-term benefits of blockchain technology, as well as how it will benefit the organisation and make their lives easier. They would also be made aware that learning about technology and how to use it would provide them with a thorough understanding of the most recent technologies that are being invented and implemented to make existing processes much more efficient. Learning about blockchain technology would allow supervisors and employees to broaden their skill set and enable and empower them to differentiate themselves from the vast pool of existing people working in nutraceutical, pharmaceutical, and other types of dietary supplement manufacturing units.

The managers need to be highly vigilant as the workers or the supervisors are responsible for entering the information into the blocks of the blockchain which would analyzed and interpreted at a later stage. The managerial implications on the implementation of blockchain technology are important for the nutraceutical industry because it deals with the health and well-being of the user. So, just as the source of raw materials, the quality control while producing and distributing the nutraceutical is important, imparting of proper knowledge and training for using the blockchain technology and interpreting the information is also important.

8. Conclusion, limitations and direction for future research

The paper proposes using blockchain technology to identify and mitigate bottlenecks in the pharmaceutical industry in order to increase efficiency and lower operational costs. In the paper, the pharmaceutical industry was used as an example for the implementation of blockchain technology, from sourcing to final product distribution. The pharmaceutical industry is distinct from other industries in that it is concerned with the well-being of a country's or group of countries' citizens. Because these citizens contribute to the overall economy of those countries, if they become ill, their efficiency suffers, reducing the nation's overall economic growth.

The blockchain is a new technology that is still being researched by experts. As a result, when implementing blockchain without disrupting the existing production system, proper strategic planning should be used. If the existing or previously established manufacturing and distribution system is disrupted, the supply of medicines into retail stores is disrupted, raising medicine prices and allowing unlicensed sellers to dominate. These sellers will sell the medicines at a price that the manufacturer does not recommend, affecting the manufacturer's revenue projections and goodwill. As a result, proper planning and having a backup plan in place in the event that the proposed plan for implementing blockchain technology fails are critical.

Future research may include the integration of artificial intelligence with blockchain technology so that people working in the nutraceutical domain do not have to manually enter the information, as there may be some incorrect data entry while doing so. It is possible to conduct research on the subject of automatically entering information.

The company that successfully implements blockchain technology from raw material sourcing to end-user distribution will gain a competitive advantage over its competitors. The process of implementing blockchain technology would yield a number of best practises, which would then be followed by a number of other businesses. It would then be added to the company's repertoire, transforming it into an intangible asset.

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.

Data availability

No data was used for the research described in the article.

Acknowledgments

The authors have no competing interests to declare that are relevant to the content of this article. The authors also have no relevant financial or non-financial interests to disclose.

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