

Systematic Review

# Blockchain Adoption in the Wine Supply Chain: A Systematic Literature Review

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**Abstract:** Blockchain offers decentralized, trustworthy and immutable data storage based on distributed ledger technology. Blockchain technology is recognized as an innovation enabler in many areas, with the food supply chain being one of them. This paper provides a systematic literature review of the current state of adoption of blockchain technology in the agri-food sector, specifically with a focus on the wine supply chain. Blockchain has the potential to improve the traceability and authenticity of the data provenance of wine products, increase consumer trust, and reduce fraud and errors. With these goals in mind, this study identifies the main research questions pertinent to the value proposition and competitive advantage of blockchain technology in the wine value chain and key players involved in the authentication and value chain recording. The PRISMA methodology was adopted to identify, screen and select only the relevant studies that were included in the analysis. This study also addresses the limitations and challenges for adoption, such as high implementation cost and lack of competences, and the need for standardized protocols and regulations. Finally, this systematic literature review includes an analysis of reports of blockchain applications in the wine sector and outlines the recommendations for future research to further explore the potential of blockchain-based solutions that could benefit all stakeholders across the wine value chain.

**Keywords:** blockchain; data provenance; food sustainability; systematic literature review; traceability; wine supply chain



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## 1. Introduction

Establishing food traceability and increasing trust in the food supply chain are fully in line with the sustainability goals recognized throughout the world. The wine supply chain is no exception. The wine industry has grown enormously in the last few decades due to a new generation of educated consumers emerging around the world. Furthermore, according to the International Organisation of Vine and Wine (OIV), the world production of wine in 2022 is estimated to be 260 million hectoliters (Mhl) [1]. This is an increase of 1%, almost 3 Mhl, from 2019. As the market has grown and more consumers are interested in buying expensive wine, the presence of wine counterfeits in the market has increased, resulting in damaged brands for winemakers and negative experiences and health risks for consumers.

Vineyards, distributors, and retailers have no means to certify the origin or supply chain information related to their products. The current food supply chain system is complex and involves multiple stakeholders across different countries; this explains the

lack of transparency and traceability required to operate and the challenges related to data privacy and security. Blockchain has been identified as a promising technology for enhancing transparency and traceability in food supply chains, including the wine industry. Li, Lee and Gharehgozli [2] conducted a literature review on the use of blockchain in food supply chains and identified several benefits, including increased transparency and traceability, improved food safety, reduced fraud and errors, and enhanced supply chain efficiency. However, the authors also noted challenges such as high implementation costs, the need for standardized protocols and regulations, and the requirement for collaboration among stakeholders. Similarly, Tsoukas et al. [3] conducted a state-of-the-art review of blockchain technology in the food supply chain and identified potential benefits such as improved transparency, traceability, and authenticity of food products, as well as increased efficiency, reduced costs, and enhanced sustainability. The authors also noted challenges related to data privacy and security, interoperability, and adoption by stakeholders.

Blockchain can be applied in many areas and industries. Novel studies have demonstrated that it can be utilized in the agriculture field, mostly for food safety, through the traceability of provenance, farming, usage in crop certification, insurance, etc. As such, blockchain-based solutions could offer benefits for different stakeholders across the wine value chain.

As mentioned above, the current food supply chain involves multiple stakeholders, and the usage of blockchain technology involves a large number of participants such as farmers, engineers, IT experts, wine producers, and buyers to perform all activities. Therefore, this paper discusses the value proposition and competitive advantages of a blockchain solution, the key players involved in authentication and value chain recording, and potential blockchain applications in the wine industry. The authors' intention in this study is to utilize a systematic literature review (SLR) to address the following research questions:

- RQ1: What is the value proposition and competitive advantage of a blockchain solution?
- RQ2: What are the limitations and challenges for adoption?
- RQ3: Who are the key players involved in authentication and value chain recording?
- RQ4: What are the main blockchain applications that can be implemented in the wine sector?

The paper is organized in the following way. After the Introduction section, which identifies the research questions, the Background covers the motivation for research on wine traceability and authenticity and explains wine value chain and blockchain in supply chain management. The Methods and Materials section describes the adoption of specific methodology for the SLR, the sources and selection of the materials included in the review. The next section provides an in-depth analysis of the selected materials. The discussion summarizes the main findings and identifies the research directions for the future. Finally, conclusions are provided at the end.

## 2. Background

### 2.1. Motivation

The motivation for this research comes from our involvement in the TRACEWINDU project that focuses on traceability in the wine industry through the integrated labeling of typicality, the health protection effect and organoleptic attributes [4]. The wine industry loses billions of Euros from counterfeit wine and illicit trades every year, and the project aims to ensure and improve the traceability of wine along the entire wine value chain, with intelligent labeling and data recording supported by blockchain technology. Such an approach could allow consumers to make purchases based on complete and reliable information about the production process and data provenance.

Understanding wine traceability and the authenticity process in the wine industry plays a crucial role in understanding the use of blockchain technology throughout the process. Many studies define traceability as a method and ability of all participants in a process to follow and verify the quality and origin of wine, including the winemaking

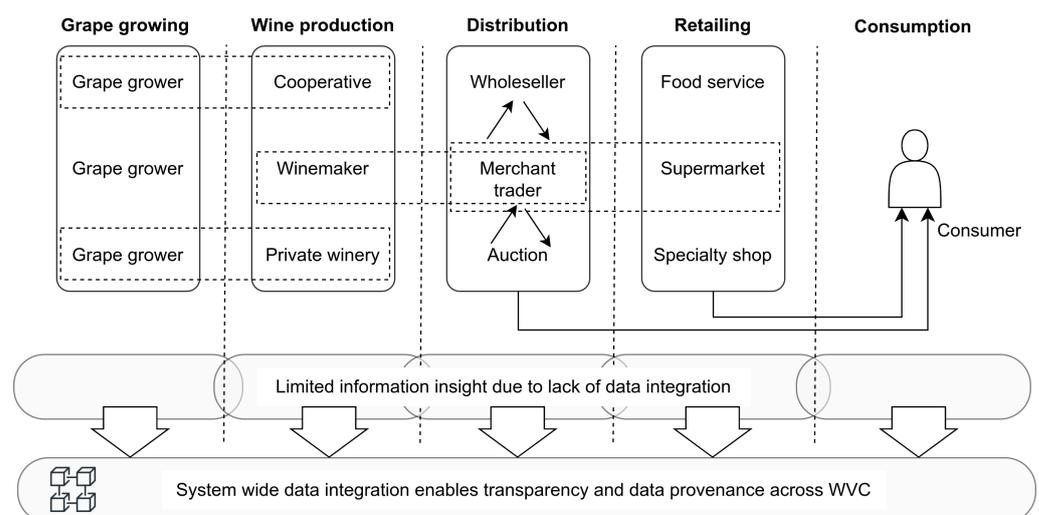
process (harvesting, crushing, fermentation, pressing, aging, and bottling), transportation, distribution and sales [5,6].

In addition, wine traceability, along with guidelines and rules laid down by responsible authorities, can guarantee wine authenticity to all stakeholders. These guidelines include several examinations, analyses and evaluations of the records kept by the wine producers (sensory evaluation, chemical analyses, monitoring, following standards, etc.) [7].

With this SLR study, we aim to point out research directions that could contribute to answering the question of how blockchain could increase trust among all the relevant stakeholders and guarantee an authentic certified wine.

## 2.2. Wine Value Chain

Wine production is a complex process that involves multiple stages, from grape growing to bottling. Each of these stages has its own challenges and requires careful consideration to ensure the quality of the final product. In recent years, there has been a growing interest in understanding the winemaking process and information exchange throughout the whole value chain and the factors that affect its performance. The following are the basic stages in the winemaking process: harvesting, crushing, fermentation, pressing, aging, and bottling. The wine value chain (WVC) can be defined as a complex network of copious participants involved in the production of wine, from the initial stage of winemaking to the consumption of wine by the consumers. Goncharuk [8] provided the framework of the WVC by defining each step and its process and actors (as seen in Figure 1).



**Figure 1.** The WVC framework: blockchain could help overcome the limited information insight of stakeholders.

These steps need to be considered in order to understand the multitude of challenges that can be encountered throughout the WVC:

- *Grape growing.* One of the most critical stages of the WVC is grape growing. Unlike other crops, grapevines require specific soil and climate conditions and a long period of preparation, including pruning and pest control. The grape-growing process is crucial for the quality of the final product, as the grape's characteristics influence the wine's flavor and aroma. Therefore, understanding the grape-growing process and its impact on the final product is essential for wine producers and researchers.
- *Wine production.* After the grapes are harvested, they undergo several stages of wine production, including crushing, fermentation, pressing, aging, and bottling. Each of these stages has its own set of challenges and requires specialized knowledge and equipment. For example, fermentation is a complex process that requires careful control of temperature, yeast strains, and other factors to ensure the wine's quality.

- *Distribution.* Once the wine is produced, it is distributed and sold through various channels, including large wine companies, specialized distribution companies, supermarkets, restaurants, and specialty shops. Wine distribution is a complex process that involves transportation, storage, and marketing. To ensure the quality of the wine during distribution, it is essential to consider factors such as temperature, humidity, and exposure to light.
- *Retailing.* Wines are typically retailed in restaurants and other food service providers, supermarkets, specialty shops, wine auctions, online stores, and other retail venues.
- *Consumption.* Finally, the consumption stage involves the treatment of the bottles and packaging waste, as well as the enjoyment of the wine by the consumer. Understanding the consumer's preferences and behavior is essential for wine producers and marketers, as it can inform product development and marketing strategies.

The WVC includes a complex network of stakeholders involved in growing, processing, and selling wine. Understanding the factors that affect the WVC's performance is essential for wine producers, researchers, and marketers. It is important to note that traditionally, these stakeholders have very limited information insight due to a lack of data integration and exchange across the value chain. System-wide data integration enables transparency and data provenance across the WVC, and this is where blockchain technology could play an important role in the near future.

### 2.3. Blockchain and Supply Chain Management

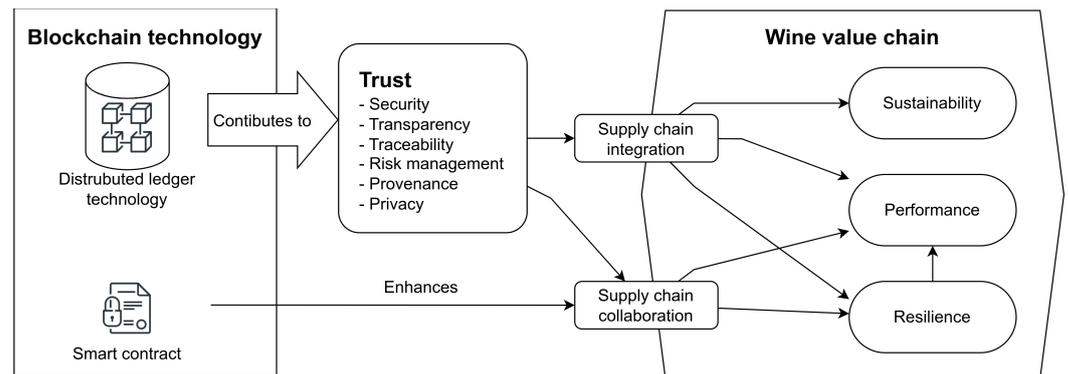
Supply chain management (SCM) is defined as a complex network with the task of managing, coordinating, and preparing the various components required by stakeholders from the raw materials to the sales and distribution of the final products and services on the market. Recent studies have identified new approaches and challenges in the SCM process that are the result of the new digital era and the use of new technologies defined as the fourth industrial revolution (I4.0): artificial intelligence, blockchain, IoT, machine learning, etc. [9]. This new digital era changes not only the use of new technologies but also the use of new business models and processes in SCM, as new technologies can be utilized for managing transactional data and information, creating links between stakeholders, and ensuring trust and transparency within the networks of stakeholders.

Blockchain technology provides data storage that is distributed all over the network of computers in a peer-to-peer (P2P) architecture [10]. The information stored in the blockchain is organized into a chain of data blocks, where each block contains bits of information that are immutably connected or chained to a single preceding block using a cryptographic hash function calculated based on the data within the blocks. Blockchain technology is therefore characterized by decentralization, immutability, security, transaction efficiency and transparency. Blockchain systems can be deployed as public, private, or federated (partly private). The technology is recognized as an innovation enabler in many areas, with the food supply chain being one of them. Blockchain is recognized as a platform that could support new business models and innovation in SCM. The decentralization of blockchain technology means that all participants in the SCM (producers, farmers, winemakers, sales managers, buyers, regulators, etc.) are connected, hold an authentic copy of the ledger, and can use data of all stakeholders as inputs to the further process, evaluation, and monitoring [11]. In addition, decentralization of the blockchain technology provides all linked stakeholders with up-to-date information in the case that an actor attempts to modify data on the blockchain, ensuring information traceability and transparency [12].

Blockchain guarantees that recorded information is stored in the ledger with protected integrity and verified authenticity and without a possibility for update at a later time. Blockchain uses a consensus protocol, which is essentially a set of rules to be followed by each participant in the network, in order to achieve a globally unified view of stored information. Guo et al. performed a comprehensive survey and analysis on blockchain and its security issues [13]. Also, an interesting approach to security and privacy-by-design framework for data management and digital transformation is presented in [14].

Vergne analyzed the benefits and disadvantages of using blockchain technology in terms of its decentralization and organization. This study states that blockchain technology decentralizes communication between participants throughout the SCM, enabling them to use information regarding past transactions and protocols and establishing trust among the linked stakeholders [11].

The study by the authors Manzoor, Sahay and Singh [15] proposed a research framework and theoretical model to explain how an organization can utilize blockchain to improve supply chain resilience and enhance supply chain performance, as illustrated in Figure 2.



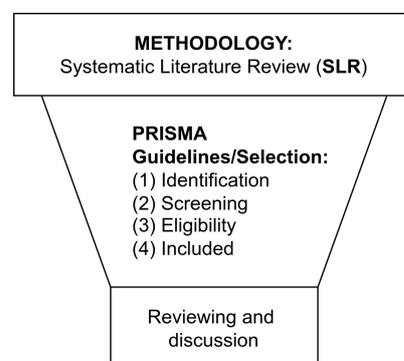
**Figure 2.** Theoretical model of blockchain technology and supply chain management.

The theoretical model developed by the authors in [15] gave propositions for the use of blockchain technology in the SCM. The utilization of blockchain in the SCM can enhance security, transparency, traceability, risk management, provenance and privacy in the process. According to the model, all these characteristics can positively impact trust among the participants.

### 3. Methods and Materials

#### 3.1. Research Methodology

After the research questions were defined, the examination of the existing literature was started using SLR with three main stages (planning–conducting–reporting) [16–19] and categorized and identified using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach, as illustrated in Figure 3. The PRISMA guidelines are a widely recognized and recommended tool for reporting systematic reviews and meta-analyses to ensure the transparency, completeness and reproducibility of the review process and findings [20].



**Figure 3.** “Funneling” approach to systematic literature review.

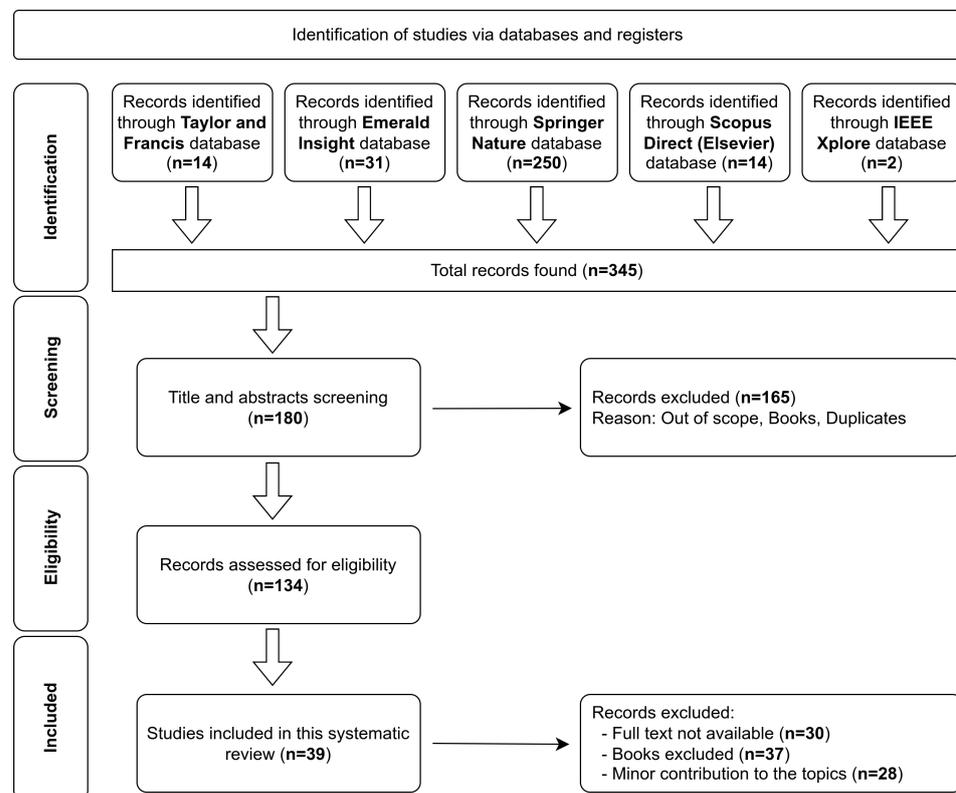
Compared to the traditional narrative approach to the literature review, SLR is a method of reviewing and synthesizing existing literature that involves a rigorous, transparent, and replicable process. It aims to provide a comprehensive, unbiased and reliable

overview of the available evidence on a specific research question or topic [21–23]. In this study, the PRISMA methodology and guidelines were used for the selection of relevant papers through the process of identifying, screening, and evaluating for eligibility and inclusion. The study focuses on past and future directions of research and innovation in the context of the use of blockchain in the wine supply chain.

### 3.2. Using PRISMA to Select the Materials

Included studies were published in the last five years, 2017–2022; blockchain technology is relatively new. The research materials identified were collected from the various databases and registers, including IEEE Explore, Taylor and Francis, Science Direct (Elsevier), Springer and the Emerald insights database, using PRISMA guidelines (Supplementary Material). In the first phase of this research (identification), we performed a search of the following terms: “wine”, “blockchain”, “supply chain”, “traceability” and “data provenance”.

As per PRISMA guidelines, Figure 4 illustrates the number of studies identified, screened, excluded and included in the review. This diagram is required by the adopted methodology.



**Figure 4.** Selection of studies to be included in the systematic review.

After 345 total records were identified, 165 were excluded from the analysis (out of scope, items identified as duplicates, clarifying the content of the included papers, and books). This resulted in 180 unique records, out of which 44 were removed from the first stage based on the fact that they were not directly relevant to this literature review. Through the screening of their abstracts, we found that they did not refer to the terms “wine industry” or “traceability”. In the eligibility phase, 95 records were excluded, 30 because the full text was not open-source, 37 because they were not on the topic or only partially included the terms of “wine industry”, and 26 because the application of blockchain was primarily referring to other sectors of agriculture rather than the wine industry. Based on the use of these four stages (identification–screening–eligibility–inclusion), 39 papers were included in this systematic literature review.

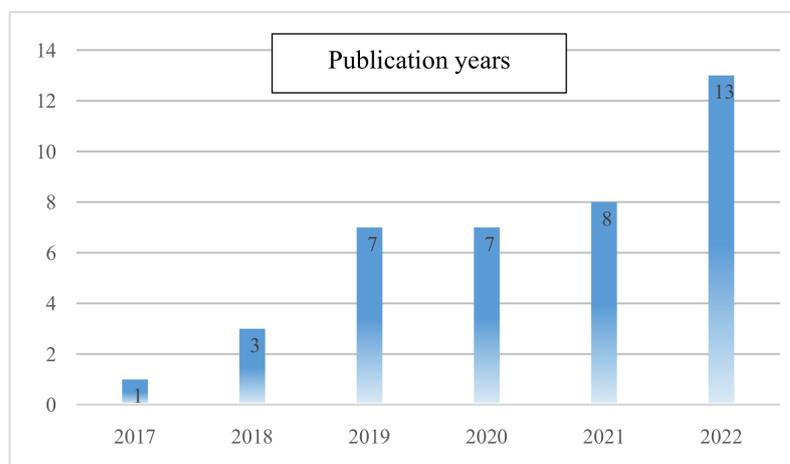
### 3.3. Results of PRISMA Adoption

Out of the entire set of literature examined for this review, 36 were articles (92%), and the rest were book chapters, reviews and short communications (8%). Table 1 contains a list of the reviewed literature by source type, referring to 19 out of 39 papers (49%). The majority of the literature utilized for this review had the following source types: Computer Sciences, Social Informatics and Telecommunications Engineering, Supply Chain Management, Food Science and Research and Technological Forecasting and Social Change, and Artificial Intelligence in Agriculture.

**Table 1.** Number of included papers organized by source type.

No.	Source Type	Number of Papers Included
1	Computer Sciences, Social Informatics and Telecommunications Engineering	6
2	Production Research	3
3	Production Planning and Control	2
4	Consumption Markets and Culture	1
5	Supply Chain Management	4
6	Logistics Management	1
7	Benchmarking: An International Journal	1
8	Operations and Production Management	1
9	Wine Business Research	1
10	Food Science and Research	6
11	Multimedia Systems	1
12	Multimedia Tools and Applications	1
13	Information Technology	1
14	Technological Forecasting and Social Change	3
15	Production Economics	1
16	Engineering and Technology Management	2
17	TrAC Trends in Analytical Chemistry	1
18	Artificial Intelligence in Agriculture	1
19	Organisational Change Management	2

Figure 5 shows the distribution of the selected papers based on the year of publication. It is interesting to note that almost 50% (13) of articles were published in 2022, while only one was published back in 2017. This indicates an increasing trend in considerations of blockchain technology in the wine industry especially with the concept of the blockchain technology as an enabler that has the potential to improve the traceability and authenticity of data provenance of wine products, increase consumer trust, and reduce fraud and errors.



**Figure 5.** Distribution of the selected publications based on the year of publication.

#### 4. Analysis of the Selected Materials

Several scientific papers have focused on different aspects of the WVC. For example, the study by Luzzani et al. [24] explored the benefits and cost of blockchain technology application in the Italian wine industry, aiming at wine sustainability management. Another study, by Adamashvili et al. [25], examined the implementation of blockchain technology in the wine supply chain and its possible impacts for the industry. Additionally, a review by Caro et al. analyzed the blockchain-based traceability in the agri-food supply chain management and provided a discussion on the aspects of practical implementation [26].

The following subsections provide an in-depth analysis of the selected materials and discuss the findings pertinent to the research questions RQ1 to RQ4 defined earlier in order to emphasize the opportunities enabled by a blockchain-based WVC-wide data platform where all of the stakeholders would be guaranteed transparency trust and data provenance.

##### 4.1. RQ1: Value Proposition and Competitive Advantage

Li, Lee, and Gharehgzoli analyzed the benefits of the blockchain in supply chain management and its participants. The authors state that blockchain technology can be integrated with other technologies, which can help capture, transfer, and process data without requiring human-to-human or human-to-computer interaction [2]. Similar discussions on the benefits and challenges related to applying blockchain in the food supply chain and traceability are given in [27,28]. The use of widely recognized studies and theories to explore the implications of blockchain in the food supply chain has been advocated by several scholars [6,29]. Cuel and Cangalosi investigated the potential effects of the blockchain on Italian wine SMEs and found that it could improve the traceability of wine products, increase consumer trust, and reduce the risk of fraud [30]. These studies and theories indicate that the main benefits of using blockchain technology in the food supply chain are to secure traceability, authenticity, transparency of data and information, and increased trust and security among stakeholders [31,32].

Most recent studies highlight the importance of understanding the technical characteristics of blockchain technology (decentralization and transparency), which play an important role when it comes to its use in the food supply chain, ensuring decentralized and transparent communication between the linked stakeholders [33]. However, just a small number of studies analyze and explore the currently available blockchain solutions and future research directions related to blockchain applications in the wine value chain. The major theoretical contributions of this study are positioned with respect to the implications of blockchain utilization in the wine industry.

A majority of research focuses on how the blockchain impacts food supply chains. Singh, Gutub, Nayyar, and Khan [34] state that blockchain integration in the food-safety traceability system allows real-time record tracking and monitoring actions in the food supply chain process, such as food location, transportation, and storage conditions. Blockchain technology also allows all participants of the food supply chain to receive notifications for data regarding food logistics and quality, which has a positive impact on trust among participants and the sustainability of the entire process.

The use of blockchain for smart contracts also has a positive impact on supply chain collaborations, as all participants included in the contracts are able to access shared data and records, increasing transparency between all parties. The use of smart contracts could positively influence supply chain sustainability, performance and resilience [15].

Agi and Jha [35] found that the use of blockchain technology in the wine industry influences the adoption-intention decision processes of supply chain participants. They explore the influence of disintermediation, traceability, price, trust, compliance, coordination, and control in the new business model process in the wine industry. Zhao et al. [31] explore the integration of blockchain technologies with other technologies of the new digital era, such as IoT in agri-food value chain management. Their study indicates that integrating technologies can improve the business model process and can aid in decision making while improving traceability, information security, manufacturing, and sustainability.

Stranieri et al. [36] demonstrate that blockchain technology positively impacts data distribution, management and preparation, which in turn helps in the decision-making processes. The authors stated that the use of blockchain technology greatly improves the two following aspects: food quality and information accessibility, availability and sharing. This study also highlights an improvement in the entire organization process, which is a result of better data and information management, increased knowledge of the firms included throughout the process, and improved competencies of stakeholders and employees.

Further, the UNDP report [37] highlights the adoption of blockchain-based solutions as a key consideration for implementing an end-to-end traceability system that is scalable, sustainable, and inclusive, ensuring that the most disadvantaged stakeholders—the small-scale producers—are not left behind, involving small wine producers.

Brookbanks and Parry [38] performed a case study analysis that examines the importance of trust in wine supply chains through the introduction of blockchain technology. Their case study examines how the introduction of blockchain technology affects trust among the participants. They demonstrated that using blockchain technology can increase trust in data by removing data and information asymmetry.

However, the introduction of blockchain technology itself is not enough to ensure trust among stakeholders, and there are many challenges in blockchain adoption and implementation that have been discussed in the literature.

#### 4.2. RQ2: *The Limitations and Challenges for Adoption*

According to the reviewed literature, several challenges have been identified, including high costs, lack of skills, ensuring trust among stakeholders, the development of competencies, manual work in the wine value chain and storage. Kumar et al. [33] emphasize the challenge of blockchain technology application to data management. They state that an important challenge lies in deciding what data should or should not be stored, as well as deciding how stakeholders can ensure data quality.

Danese, Mocellin and Romano [39] present a multiple-case study of five Italian wine companies and state that one of the challenges is implementation difficulties. Many processes are implemented manually, and the use of IoT, which generally helps to solve issues related to data collection with blockchain technologies, can be difficult to apply. Further, they stated that wine cellars are commonly underground, where connectivity is poor and the environment is not ideal for the functioning of electronic devices. As in the food supply chain, one of the biggest challenges for blockchain is its degree of adoption in wine supply chain processes [40]. The adoption of the blockchain requires new roles, understanding and skills that are necessary to support all of the aspects of blockchain technology adoption. Technical skills and limited knowledge on the use of blockchain and digital tools in general can represent a barrier to its adoption [41–45].

In accordance with the above, the introduction of blockchain technology in the wine industry and supply chain management impacts decision making in management, distribution and data sharing. Blockchain technology enables digitalization and automation in the process of the wine value chain and enhances security and performance in the new business model [43]. Tiscini et al. [46] performed a case study of the use of blockchain in a small-sized winery and examined the impact it has on introducing new innovative business processes in the wine industry. Innovative business processes include the use of new technological solutions in the marketing process, such as the rebranding of the products (winemaking and bottling procedures) [47].

As evidence shows, for the blockchain to provide value to supply chains, data and information need to be transparent and easily exchanged between different supply chain stakeholders: wine producers, retailers, distributors and consumers. Data and information transparency need to be ensured. Furthermore, authenticity needs to be ensured by protocols, standards, and regulations by the national authorities in the wine industry [48–50].

#### 4.3. RQ3: Key Players Involved in Authentication and Value Chain Data Recording

Data play an essential role in creating a transparent wine supply chain, which is crucial for providing traceability and accountability of the product from vineyard to consumer. The data that can be used in the wine supply chain include a wide range of information, such as grape variety, vineyard location, farming practices, harvesting dates, transportation, and storage conditions. Additionally, details on the winemaking process, including fermentation and aging, can also be included in the dataset. Certification and third-party audits are also conducted to ensure compliance with industry standards and regulations. Access to information by different stakeholders can be achieved through labels, online platforms, and mobile applications, enabling them to make informed purchasing decisions and to give feedback on product consumption. The data can also be made available to all stakeholders across the value chain, including winemakers, distributors, retailer stores, and regulators, to ensure transparency and prevent fraud. Therefore, stakeholders in the wine supply chain are responsible for tracking records throughout the entire process, creating links between the participants of the process, thus ensuring traceability and authenticity in the quality management system [51].

Data that can be collected through the wine value chain include the following.

- Farming: soil data, fertilizer use, pesticide use, equipment use and maintenance, energy consumption, weather measurements, chemical and sensory testing, control of grape ripeness and maturation, and grape harvesting date.
- Winemaking: data on the grape's origin and inbound operations, pressing and fermentation operation, additive use, sanitary procedures, process parameters monitoring and analysis, chemical and sensory testing, and tank operations.
- Packaging and distribution: bottling process data and analysis and the selection of relevant datasets, the activation of products' digital twins, the activation of producing digital content, and the monitoring of product transportation.
- Marketing and sales: the selection of datasets and claims to be shared, browsing product digital content, customer digital interaction, and other customer engagement programs (survey, loyalty, etc.).

Several scientific papers published in the last five years support the importance of data in a transparent wine supply chain. A study by Agnusdei et al. [52] examined the impact of traceability on the Italian wine sector, highlighting the importance of data in providing consumers with information on the origin and characteristics of the product. Another study by Sun et al. [53] analyzed a series of procedures for wine classification and identification and data processing methods used to help wine researchers choose appropriate methods to meet the challenge and ensure wine traceability and authenticity. Finally, Biswas et al. in [54] discussed the importance of data in ensuring the sustainability of the wine industry, proposing a blockchain-based wine supply chain traceability system for enabling transparency, accountability, safety and security in the overall process from the grape to the bottle.

#### 4.4. RQ4: Blockchain Applications in the Wine Sector

This part of the paper explores use cases and technologies proposed in the literature. In general, all platforms and data can be divided into several categories: (1) winemaking and producing, (2) wine distribution and storage (3) delivery, and (4) sales and consumption. The introduction of blockchain technology and its platforms needs to involve all participants in wine supply chains, from grape growers to consumers. Platforms need to ensure the quality of data and information provided by all participants and stakeholders in the supply chain. Furthermore, platforms and technologies represent a medium between all participants and stakeholders in the wine industry.

Tokkozhina, Ferreira, and Martins [55] explore increasing brand reputation by ensuring the origin of wine from the manufacturer to the final consumer. The authors examine blockchain technology and the implementation of smart contracts as a method to track all

records, data, and transactions of the final products from the moment of grape harvesting to the moment of decision making by the final consumer. In the study, the authors describe a framework model with blocks and data that can be tracked in the wine supply process and used as an innovative technological solution in the process of decision making, as well as in other processes in the supply chain.

Agnusdei et al. [52] propose their framework for the wine supply chain based on the integration of blockchain technologies and other communication and information technologies such as Radio-Frequency Identification (RFID) and Near Field Communication (NFC) tags, Serial Shipping Container Codes, and Quick Response (QR) codes. They also conclude that the use of smart contracts can provide traceability and simplicity. They also suggest the integration of technologies in order to assess the level of end consumers' trust and satisfaction with the solution. Gayialis et al. [56] also present the application of a smart-contracts-enabled blockchain traceability system designed for the wine supply chain and which operates through the Ethereum Network.

Popovic et al. [57] address the considerations related to the integration of blockchain technology with other technologies such as IoT, Cloud, and mobile technologies through the use of custom-designed smart tags. They also examine the use of integrated technologies applied to each bottle of wine in order to provide track-and-trace functionalities [58]. Their study examines how integrated technologies improve transparency and data provenance in the food value chain, with a specific focus on the wine industry.

Implementing new approaches and frameworks can lead to the development of new innovative solutions for improved traceability, transparency, and provenance in the wine industry. Most studies suggest the integration of blockchain technology with other technologies in order to store and track data and information from earlier phases of the wine supply chain (i.e., grape harvesting) to the final consumer.

## 5. Discussion

The use of blockchain in the wine industry can help address many of the challenges faced by the supply chain, including traceability, data immutability, and trust creation. The literature suggests that this technology can positively impact the profit and ROI of supply chains, improve the quality of products, and foster better information management. However, the adoption of blockchain-based solutions in the wine industry requires new roles, responsibilities, and skills, which can be a barrier to adoption. Challenges in storage capacity, scalability, privacy leakage, high costs, and regulation also need to be addressed.

In line with the research questions set in this paper, we can summarize the findings as follows.

- The implementation of a blockchain-based data platform that would collect data across the WVC could be beneficial for all the stakeholders involved and offer a competitive advantage. Having transparency and data-provenance-ensured, blockchain-based solutions could benefit the wine sector, especially in the domain of counterfeit prevention and authenticity. Such technology also creates opportunities for applications based on incentives and gamification, which could motivate stakeholders and enable the creation of different added-value apps.
- As indicated, there are many challenges related to blockchain technology adoption related to technological issues, but also related to the readiness of stakeholders to engage in the creation of such systems: lack of skills, high costs, competences and trust among stakeholders. However, most of the literature suggests that data-information transparency is very important in order to be able to ensure the authenticity of the products. Furthermore, the challenges could be easier to overcome with support from protocols, regulations, and standards defined by the national and international authorities in the wine industry.
- The paper indicates the key players involved in creating a transparent WVC in order to provide traceability and accountability of products from vineyard to consumers. A WVC-wide data platform is needed in order to create smart solutions that could offer

data-driven augmented intelligence for all stakeholders in the value chain necessary to improve their decision-making process.

- Finally, this SLR offers insight into blockchain applications that can be implemented in the wine sector. The platforms discussed can be divided into categories related to winemaking, distribution and storage, delivery, and sales and consumption. Implementing a transparent and WVC-wide, blockchain-supported data platform creates opportunities for innovative applications.

On the one hand, the contribution of this study was to document the diversity in underlying theories and empirical studies that facilitated the advance of blockchain technology adoption in the wine industry while addressing the benefits and value proposition, challenges and limitations, key stakeholders, and possible applications. On the other hand, from this analysis, we can derive the following research directions: (a) empirical research on various blockchain applications in the wine sector and the evaluation of technological benefits and challenges to the implementation and integration of these solutions into the WVC; (b) theoretical and empirical research on how to enhance the overall competitive performance of wine production and improve the effectiveness, resilience and sustainability of the WVC (increased trust, collaboration and competitive advantage); (c) theoretical and empirical research aimed at the development of new and innovative business models enabled by blockchain adoption; and finally, (d) how to tackle the issue of readiness of stakeholders to adopt the blockchain and engage in digital innovation based on this technology and innovative business models.

The authors of this paper noted a few limitations to this study. Only a limited number of papers were reviewed in detail in order to derive insights, given that the introduction of blockchain technology in the wine industry is a relatively new area. Nevertheless, this SLR contributes by providing new state-of-the-art insight regarding the introduction of blockchain technology in the wine industry.

Finally, the SLR analysis indicates that there is a growing interest in blockchain technology and that it could be playing an important role in overcoming the challenges due to the lack of data integration and information exchange across the WVC. Blockchain technology could help implement WVC-wide data platforms where all of the stakeholders would be guaranteed transparency trust and data provenance.

## 6. Conclusions

Overall, the benefits of blockchain technology in the wine industry are promising, and the technology has the potential to simplify partner relations, reduce transaction costs, minimize trade risks, and facilitate access to trade finance. The main motivation behind this research was to point out research directions on how the blockchain can contribute to WVC performance, resilience, and sustainability. The main contributions of this paper can be summarized as follows:

- The wine supply chain involves multiple stakeholders, and the adoption of blockchain technology involves a large number of participants, such as farmers, engineers, IT experts, wine producers, and buyers, to perform all activities. Blockchain technology is recognized as a technology enabler that allows digital innovation throughout the value chain.
- The main research questions addressed in this SLR were defined in order to analyze the competitive advantage of blockchain in WVC, limitations and challenges, key stakeholders, and main applications in the wine sector. The PRISMA method was adopted to identify, screen, evaluate, and select the publications to be included in the review process and analysis in order to address the research questions.
- The PRISMA method resulted in 345 total records, and with the screening process and evaluation for eligibility, and at the end of the “funneling” process, 39 papers were included in this SLR. The process also revealed a growing trend in publications in this field, since almost 50% of publications were in the last year within the whole 5-year period.

- Blockchain-based solutions could benefit the wine sector, especially in the domain of counterfeit prevention and authenticity, but there are also opportunities for solutions based on incentives and gamification aimed at new and innovative business models.
- The study identifies the challenges related to the adoption of blockchain in WVC solutions that can be related to technological issues and potentially high costs of implementation.
- There is also the level of readiness of all stakeholders across the WVC to adopt the blockchain, reflected in the lack of skills, competencies, and trust among involved parties. Therefore, it is very important that further research addresses socioeconomic aspects in order to improve the readiness of stakeholders to adopt blockchain technology and innovative business models based on digital innovation.
- Future research includes exploring the potential of blockchain applications for a sustainable business model innovation in the wine industry and examining how assets can be transferred between supply chain players. In the near future, we will focus on practical implementations and the testing of blockchain applications in the industry setting, most notably with respect to SME-sized wineries and wine distributors, in order to propose a conceptual framework for innovative business models in WVC based on blockchain data provenance.

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## Abbreviations

The following abbreviations are used in this manuscript:

4IR	Fourth Industrial Revolution
BT	Blockchain Technology
DAML	Digital Asset Modeling Language
IoT	Internet of Things
IT	Information Technology
NFC	Near Field Communication
OIV	International Organization of Vine and Wine
Mhl	Million Hectoliters
PRISMA	Preferred Reporting Items for Systematic Literature Review and Meta Analysis
QR	Quick Response
RFID	Radio-Frequency Identification
ROI	Return on Investment

SCM	Supply Chain Management
SCRES	Supply Chain Resilience
SLR	Systematic Literature Review
SME	Small and Medium Enterprise
SSCC	Serial Shipping Container Codes
UNDP	United Nations Development Programme
WSC	Wine Supply chain
WVC	Wine Value Chain

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