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IoT technologies for wine supply chain traceability: potential application in the Southern Apulia Region (Italy)

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Abstract

The high value and volume of Italian wine production determines a strong stimulus for counterfeiting, which generates negative consequences for grape growers, winemakers and consumers. In this context, IoT technologies and the blockchain can serve as tools to ensure traceability, transparency and efficiency along the whole wine supply chain.

Using primary data collected through interviews to the main grape growers and wineries involved in the wine supply chain in the Southern Apulia Region and secondary data, acquired from previous scientific literature, the study proposes a framework for the traceability and efficiency of the wine supply chain based on a combination of blockchain, Radio-Frequency Identification (RFID) and Near Field Communication (NFC) tags, Serial Shipping Container Codes (SSCC) and Quick Response (QR) codes. The developed framework allows for the systematic storage of information about commodities and processes throughout the supply chain, from grape growers to wine consumption and packaging disposal and/or reuse (forward and reverse flows). In addition, it ensures the transparency, safety, and security of all processes involved within the wine supply chain, serving as a quality information management tool. The information collected along the wine supply chain is entered into the management system by farmers, winemakers and bottlers and is accessible to all of them, while the distributors, consumers and the bottle reverse logistics operators, can only consult all of the information stored on the blockchain in order to know the origin, the quality, the processing and the authenticity of wines, without being able to enter data and/or modify the existent information.

Keywords: grape growers; winemakers; blockchain; RFID tags; NFC; counterfeiting

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1. Introduction

Globally, Italy has always been one of the main players in the wine sector. It is leader in production volume and ranks second for export volume and value. Italy is also first in terms of the number of geographically denominated wines, which account for 58.2% of the total wine production and for about 88% of the total wine export value [1, 2, 3]. The large share of high-quality wine produced by the Italian wine industry and the increasing reputation of Italian wines on domestic and foreign markets contribute to creating significant occasions for frauds [4]. Frauds can relate to any phase of the wine supply chain. Among the vast types of fraud, the counterfeiting and relabeling of cheaper wines as expensive, rare and collectible wines is the most prevalent [5]. The actors involved in the wine supply chain are thus paying more attention to preventing every kind of counterfeiting. By adopting new technologies which enable traceability, anyone would be able to check and verify each phase of the whole wine supply chain, from vineyard cultivation to wine consumption and packaging disposal, including reverse logistics processes [6].

With the advent of the Internet of Things (IoT) technologies, several traceability tools have been developed to track supply chain activities: barcodes, Quick Response (QR) codes and Radio-Frequency IDentification (RFID) tags [7]. Barcodes are a one-dimensional pattern of parallel spaces and bars arranged to represent 10 digits. The encoded information can be read by an optical scanner that sends the data to a system where they are stored and processed. The QR code is a typical two-dimensional barcode and is commonly used in traceable labels because it can store more information than one-dimensional bar codes [8]. RFID is similar to barcoding because data from a tag or label are captured by a device and stored in a database, but it is more advantageous than systems which use barcode asset tracking software [9]. The most notable advantage is that RFID tag data can be read outside the line-of-sight, whereas barcodes must be aligned with an optical scanner. Moreover, it has larger storage capacity (around 32-128 Bit) and can be continuously updated, ensuring the highest level of security compared to previous solutions [10].

The integration of IoT technologies with the blockchain ensures the traceability and the complete transparency of the supply chain. As a distributed and decentralized technology, the blockchain is a set of time-stamped blocks that are linked by a cryptographic hash. It has been widely accepted as a solution to avoid the tampering with information collected across the whole supply chain [11, 12, 13]. Blockchain technologies, thus, help to build trust mechanisms for solving transparency and security issues, so that no single party in the supply chain can alter the existing information [14].

Within this context, traceability is becoming an essential management tool also for improving production efficiency. In fact, traceability enables an effective process control and allows for the elaboration of reliable risk assessment models, aimed at identifying factors that cause quality and safety problems [15]. Requiring more agile planning approaches, traceability can play an important role in promoting management and dynamic pricing.

Proposing a framework for traceability and efficiency within the wine supply chain in Southern Apulia region, the present study answers the following research question:

RQ: How can IoT technologies support traceability within the wine supply chain?

Based on the existing knowledge extracted from the scientific literature, the developed framework allows for the systematic storage of information regarding commodities and processes throughout the supply chain, from grape growers to wine consumption and packaging disposal and/or reuse (forward and reverse flows). In addition, it ensures the transparency, safety, and security of all processes involved within the wine supply chain, serving as a quality information management tool.

The remainder of the study is organized as follows: Section 2 describes the wine supply chain entities in the Southern Apulia Region and explains the possible IoT solutions to support traceability and efficiency. Section 3 presents the proposed IoT-based traceability framework. Finally, Section 4 discusses and concludes.

2. Background

2.1. Wine supply chain in the Southern Apulia Region

The Southern Apulian vineyard area for the production of wine grapes amounts to approximately 38 thousand hectares. Annually 10 million hectoliters of wine are produced, with a greater incidence of table wine, compared to the production of Denomination of Controlled Origin (DOC) and Typical Geographic Indication (IGT) wines. Apulia is the main wine producer in Italy and contributes about 20% of the entire national production [16].

For the following analyses the wine supply chain in the Southern Apulia Region (provinces of Taranto, Lecce and Brindisi) were considered, in which approximately 2,1 million hectoliters of wine are produced [16].

In these specific zones, the wine production chain is divided into three macro production processes, managed by different actors: (i) vineyard cultivation, (ii) winemaking and (iii) wine bottling (Fig. 1).

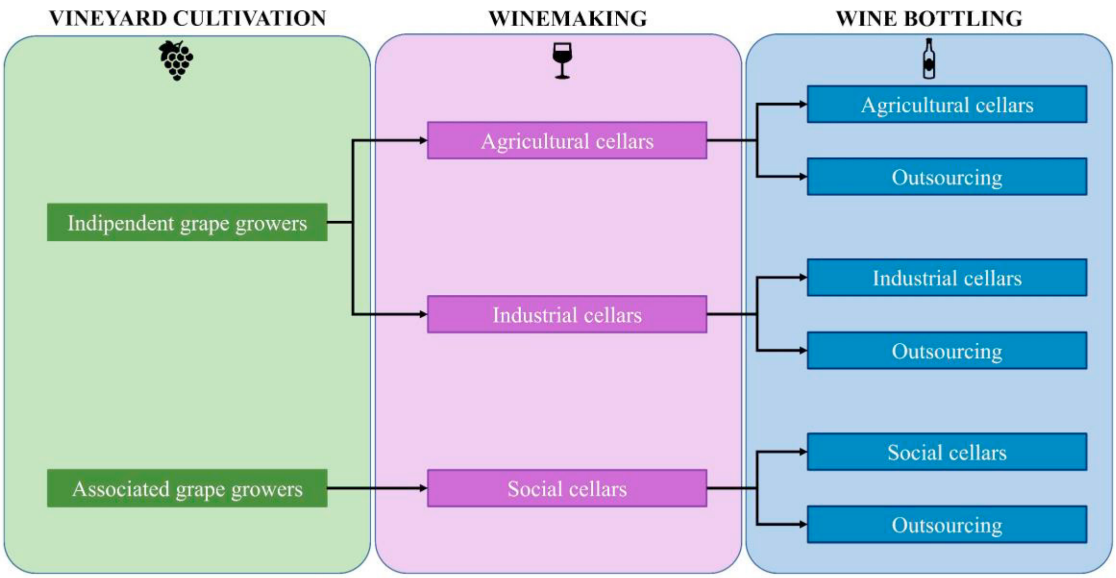

Figure 1 – Traditional wine production chain

The vineyard cultivation process can be managed by associated viticulturists, who confer all the grape production to cooperative or social cellars, or by independent viticulturists, who can decide to carry out the winemaking activities independently or to delegate it to third parties [17].

Winemaking processes can be performed by Agricultural cellars, which vinify grapes mainly of their own production, by Industrial cellars, which vinify mainly grapes on behalf of third parties, or by Social Cellars which are wine cooperatives that vinify grapes from associated farmers.

Wine bottling can be performed directly by cellars (agricultural, industrial and social) or outsourced to companies that deal with the bottling. The described production chain appears extremely fragmented and involves numerous actors. Its configuration generates issues in the traceability of the individual phases and therefore, in the reliability of the information in all the phases of supply chain.

2.2. Traceability in food supply chain

Several different definitions of 'traceability' can be found in the existing scientific literature [10, 18, 19]. Since the focus of this study is the use of IoT technologies and the blockchain for traceability, the Bosona and Gebresenbet [10] definition was adopted. It states that traceability is directly related to logistics activities through the capturing, storage and transmission of information regarding each stage of the food supply chain (FSC). Recently, FSC research efforts have been focused on facing challenges through IoT and the blockchain. In particular, Li et al. [20] propose an information architecture based on an IoT platform for product tracking and tracing, which provides critical beneficial services to the monitoring of the pre-packaged food supply chain and consequently allows for the adoption of relevant and informed decisions. Similarly, Pal and Kant [21] present a detailed infrastructure to implement an IoT-based sensing and communication platform in a food supply chain, discussing the specific data needed to be collected along with the most suitable technologies to acquire them. Jabbari and Kaminsky [22] discuss, instead, the nature of blockchain systems and how they could affect the food supply chain. Several benefits are highlighted such as ensuring trust between the user and system, removing the need for a third party to ensure trust, and allowing individual ingredients to be traced back to their origin. The easy duplication of RFID tags and tampering with sensors are the most complex open issues. Montecchi et al. [23] state that the provenance of each product could be established using a blockchain-based food supply chain. Since most of the information regarding a product is accessible only to businesses and not to the consumers, this can also result in the offsetting of the existing information asymmetry. Kamilaris et al. [24] discuss the impact of a blockchain-based food supply chain in the agriculture market, while Luvisi et al. [25] propose a system based on RFID microchips and professional geographic software aimed at optimizing the vineyard management. Even though wine supply chains are subject to different regulations (European and national laws), wine authenticity is not always guaranteed, and frauds are widespread. In the scientific literature there is a lack of technological solutions developed to improve the traceability and efficiency of the entire wine supply chain. Moreover, only larger firms adopt traceability technologies while smaller ones, traditionally involved in the different stages of the wine supply chain, rarely implement technological traceability tools [26]. Hence, the technological improvement in the field of traceability, aimed at validating the origin and quality of wines, is fundamental to protect wine producers and consumers [27]. Thus, the novelty of this study mainly lies in the development of a framework which, ensuring low investment and management costs and easily implementable technologies, prove to be applicable and suitable for the wine actors operating in the Southern Apulia Region.

3. The proposed framework

The study methodology consisted of two main phases. In the first phase, qualitative interviews were carried out to a sample of 24 grape growers and wineries located in the Southern area of the Apulia Region in Italy (Fig. 2) between March and June 2021.

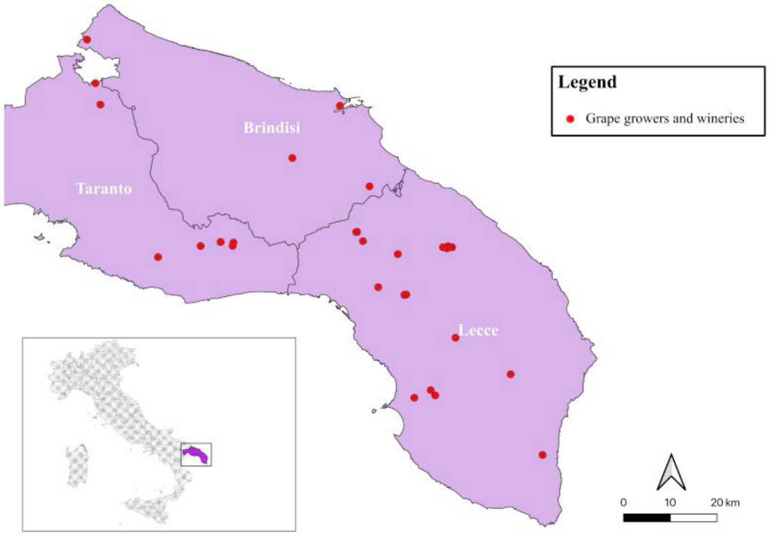

Figure 2 – Grape growers and wineries in the Southern Apulia Region

The semi-structured interviews aimed at acquiring information about the characteristics (actors involved, technologies adopted, equipment, timing, etc.) of each phase of the supply chains. Primary information gathered by the main actors of the wine supply chain (i.e., farmers, producers, distributors, resellers) was critically analyzed in order to identify the main features of the wine supply chain and the potential of IoT technology implementation for improving efficiency and traceability.

In the second phase, through a "snowball" approach [28], secondary data were acquired from the literature contained in Scopus and Google Scholar scientific databases, aiming at elaborating a conceptual framework to answer the study research question. Sourcing from the scientific literature, data on technologies currently applied to the agri-food supply chain useful for making the wine supply chain more efficient were acquired.

Figure 3 illustrates the proposed framework for the traceability of the wine supply chain in the Southern Apulia Region, which includes a combination of different digital technologies, i.e., the blockchain, Internet of Things, RFID/NFC tags, Serial Shipping Container Codes (SSCC) and QR codes, to be potentially applied within the different supply chain stages.

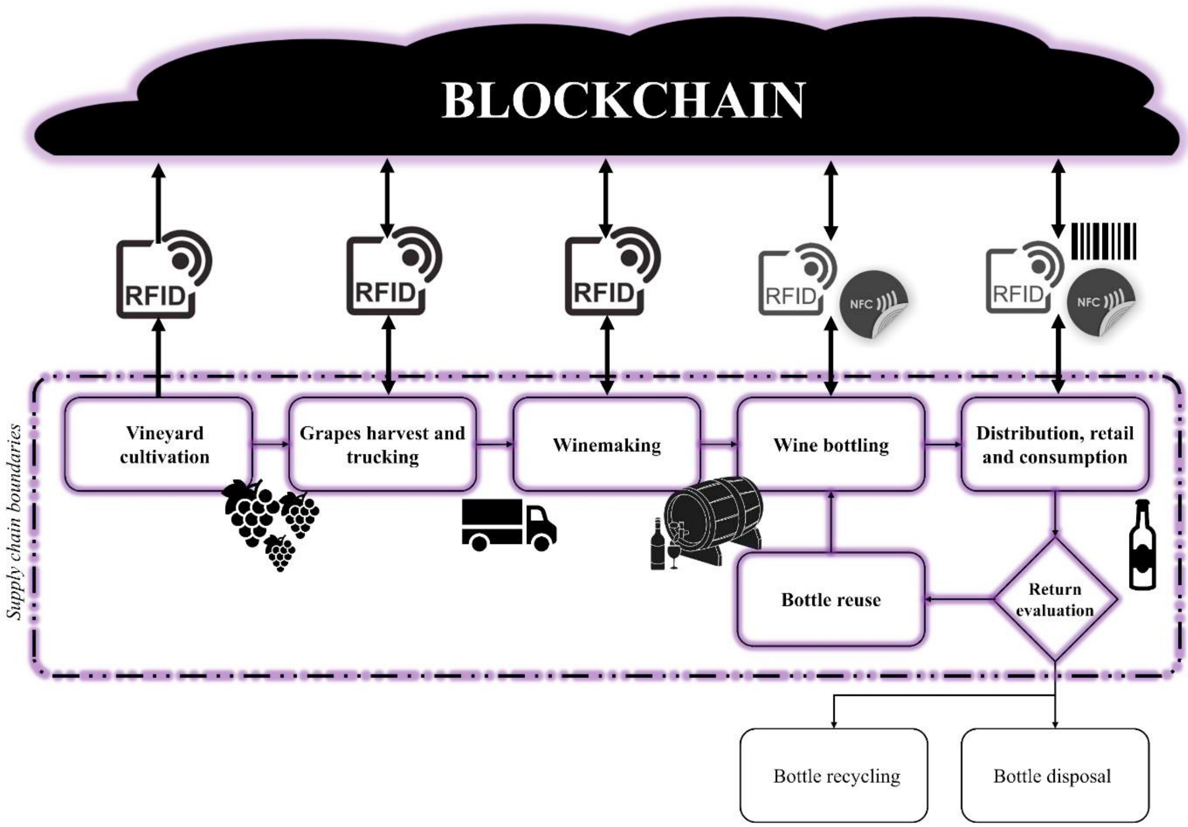

Figure 3 – Blockchain supply chain

3.1. Stage 1: Vineyard cultivation

IoT solutions can be implemented starting from the vineyard cultivation stage, only if grape growers choose to adopt precision farming (PF) [29]. The latter is a site-specific production and management approach based on the optimization of each single vineyard or portion of it [30, 31]. PF applied to viticulture offers methods to map spatial variability using advanced geomatic technologies (i.e., Global Positioning System - GPS and Geographic Information System - GIS) and monitoring sensors (i.e., RFID microchips).

A RFID/GPS system can be designed with a radio-modem for data transmission to a data center for post-processing where data can be registered and evaluated using GIS analysis software. In particular, vines containing a RFID microchip can be identified by a code, associated with the microchip, and they can be located by a GIS on a three-dimensional electronic map, recreating a virtual vineyard [25, 32]. This system allows (i) for the remote monitoring of vineyards; (ii) for the archiving and managing of useful data associated with vines, using technical and plant health files; and (iii) for the supplying of a durable, safe and detailed vineyard information map. Through PF it is possible to monitor the vineyard environment and support fertilization decisions.

A cloud computing software can process the information collected by RFID and GPS through blockchain technologies, ensuring data reliability and security and the start of a traceability process in the wine supply chain.

3.2. Stage 2: Grape harvesting and trucking

Within the study area the grapes are traditionally harvested and transported in plastic boxes and/or directly on truck beds. At this stage of the wine supply chain, applicable IoT-based technologies are increasingly complex and reliable. The most widespread are QR codes and recently, RFID tags. Differently from the former, RFID technology fits better with the traceability needs of the proposed framework, due to its greater recognition flexibility and efficiency. Ultra-High Frequency RFID tags, readable at long range, can be applied on the plastic boxes and/or the truck bed to uniquely identify the main features of the transported grapes, such as the variety, the origin, the cultivation techniques etc., but also other more specific information, such as the single vineyard from which the grapes come and their oenological parameters, etc. [33, 34].

3.3. Stage 3: Winemaking

When the harvested grapes arrive at the cellar, they should cross a sort of gate that reads the RFID tags applied on the boxes or on the truck bed, before being sorted for the destemming and pressing. The gate can simultaneously read many RFID tags, which are located about 6-7 meters away. In addition to the information already collected during the previous stages, RFID tags can be updated with data regarding the arrival time and the quantity of the grapes delivered. The latter are recorded on a cloud computing software and updated on the blockchain.

During the winemaking process, all movements within the cellar, oenological treatments (additives, filtering, other processes) and decanting are tracked. Using an RFID reader/writer, the cellarman can manually record all the information, updating the blockchain.

3.4. Stage 4: Wine bottling

During the bottling and labelling phases, counterfeiting of packaging concerns the use of materials that do not comply with the legislation on food contact materials (Regulation (EC) No 1935/2004) and which can have negative effects to consumer health [35]. In order to avoid the risk of fraud, RFID/NFC hybrid tags can be applied under the traditional paper label. RFID technology allows the winemaker to streamline the update and management processes, while NFC technology allows consumers to easily acquire the information regarding each phase of the wine supply chain through their smartphones. After bottling, single bottles are grouped into loading units (pallets or boxes) for distribution.

3.5. Stage 5: Distribution, retail and consumption

Within the transactions between winemakers and wholesalers and/or retailers, smart contracts are recommended to reduce transaction time, while, at the same time, preserving security. A unique QR code or a Serial Shipping Container Code (SSCC) can be associated and applied to each loading unit to be traced, and then scanned and entered into a specific purchase order. The retailers or wholesalers can acquire information regarding the bottles and their whole supply chain by scanning the QR code or SSCC applied on each loading unit used to facilitate storage management before retail [36]. The end-users/consumers through a specific application on their smartphones could scan the RFID/NFC hybrid tags under the bottle labels to check wine authenticity and to acquire all the information stored through the blockchain.

3.6. Stage 6: Bottles reverse logistics

After consumption empty bottles need to be evaluated in order to determine if they should be disposed of, recycled or reused. The bottles suitable for re-use continue to be traced along the supply chain (reverse flow). In this case, the information contained in the RFID label allows the empty and sterilized bottles to be easily redirected to the original bottler, who generally needs to adapt the shape and size of bottles to the technical specifications of the wine, as well as to branding and market recognition [37, 38, 39, 40].

4. Conclusions

This paper proposes the application of an IoT technologies-based traceability system for the wine supply chain to provide transparency, efficiency, provenance, safety and security. Since there has been an increase in the counterfeiting of wines in the global market, traceability is an effective solution to overcome this problem. Starting from a first exploratory analysis and systematization of the wine supply chain in the Southern Apulia region, the weaknesses of the system were identified, and suitable technological solutions were proposed to support efficiency and traceability. In particular, the analyzed supply chain is fragmented and involves many actors. In many cases, they try to optimize their own objectives leading to asymmetric information by keeping some strategic information private. This could favor counterfeiting and food fraud activities, not protecting the quality of local products, with consequent damage to consumers and to the food label market.

The proposed framework, based on the use of RFID tags, RFID/NFC hybrid tags, QR codes and SSCCs, leads to potential benefits for each actor of the wine supply chain in terms of efficiency and effectiveness in operations and traceability. The information collected along the wine supply chain is entered in the management system by farmers, winemakers and bottlers and is accessible to all of them. Instead, the distributors, consumers and the bottle reverse logistics operators, can only consult the information stored on the blockchain in order to learn the origin, the quality, the processing and the authenticity of wines, but are not able to enter data and/or modify the existent information.

A potential development of this study could consist in a practical experimentation and application of the proposed framework to check its external validity and traceability performance across the various scenarios deriving from the different wine supply chain configurations.

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