Blockchain applications in the food industry: a pilot project implementation in the ancient grains industry

Bianca Bindi[1], Gloria Padovan[1], Giacomo Trombi[1], Niccolò Bartoloni[1], Virginia Fani[1], Marco Moriondo[2], Camilla Dibari[1] and Romeo Bandinelli[1]

[1] Univerrsity of Florence, Italy
[2] CNR, Italy
romeo.bandinelli@unifi.it

Abstract. The purpose of this paper is to present the results of a pilot project implementation of PLM solution based on blockchain technology in the ancient grains Italian Industry. After a literature review on previous experience of blockchain technology in the food Industry, a case study analysis has been done to identify the actors along the supply chain of durum wheat for pasta production, as well as to study the main regulations for wheat production. Moreover, possible weaknesses and strengths in the application of the blockchain for the ancient wheat supply chain have been highlighted. Finally, the main evidences of the pilot project are reported and a set of information systems able to manage the product lifecycle have been identified. The paper provides valuable insights to companies that are trying to implement such solution in the food Industry.

Keywords: Blockchain, Ancient Grain, Food Industry, PLM.

1 Introduction

Recently, blockchain technology has been introduced in the field of food safety to trace food information. Blockchain is a distributed computing paradigm characterized by decentralization, network-wide recording, low cost, high efficiency, security, and reliability. It can reduce administrative costs, trading risks, improve information credibility, increase regulatory transparency, and implement trusted processes. Using blockchain in food supply chain can potentially eliminate information asymmetry, achieve the synchronous updating of information across all nodes of the supply chain, eliminate product quality problems caused by stakeholders, and strengthen information credibility.
The study aims to build an ancient grain Product Lifecycle Information (PLM) management solution based on blockchain technology. In detail, starting from a literature review, a single case study has been carried you to identify the key nodes and the actors of the durum wheat for pasta production supply chain. Moreover, main regulations and standards for wheat production have been analyzed. Last, a set of information systems have been identified to manage the product information along the whole product lifecycle.

The main contribution of the paper is the definition of a framework and a set of guidelines to replicate the pilot application of the blockchain in the wheat supply chain, using a “from field to fork” approach in order to manage the whole product lifecycle.
The paper is structured as follows: Section 2 presents a literature review on agri-food supply chains, with a focus on the ancient grain value chain. Section 3 introduces the pilot project, while section 4 highlights some of the results. Finally, section 5 presents the conclusions and future steps.

2 Industrial background

2.1 The ancient grain supply chain

The grains industry has an important role in the worldwide economy, due to the large quantity produced and its role in the its role in the food supply chains of all countries. Within this industry, ancient grains have grown steadily over the last 10-15 years. The total gross value has been estimated at 457.35 M$ in 2022 and is expected to reach 6.3 B$ in 2026. In Italy, the cultivation of durum wheat continues to be a key element of our agriculture, mostly characterised by high quality and exclusive foreign markets.

From a global perspective, countries outside Europe (e.g. Turkey) have significantly increased their production capacity, offering products at competitive prices but with high quality or environmental standards. Traceability, quality and environmental soundness are critical factors for Italian pasta producers, both for domestic and international markets.

The ancient grain do not use fertilisers, pesticides and intensive labour, with lower costs and consequently lower production rates. As reported by several authors, its consumption brings health benefits to the consumer. Moreover, the rediscovery of old varieties of ancient cereals allows a better response to today's important challenge of activating responsible practices and sustainable consumption.

As reported in the literature, ancient grain is a specific type of cereal that is not suitable for the application of modern agricultural practices.

Although the supply chain of ancient grain is short and simple, it involves a series of coordinated actions and efforts carried out by farmers, millers and wheat processors (pasta makers, bakers and chefs). In this SC, the central role is played by the mill, which is responsible for the quality of the raw material, the sharing of knowledge and all those relationships that allow all actors to adopt a win-win strategy in order to achieve financial and non-financial mutual benefits.

2.2 Blockchain application in the agri-food Industry

Blockchain food traceability is currently one of the most interesting topics in the global agri-food segment. Several contributions can be found regarding barriers and benefits of its application to trace different types of products.

[1] report more than 90 papers published between 2016 and 2021 on this topic. Perceived benefits of blockchain application relate to traceability, minimising food fraud

and supply chain monitoring [2-3-4], increasing transparency [2], integrating IoT devices [5] and eliminating intermediaries, reducing transaction costs [6]. Despite this, only a limited number of applications and case studies described as pilot projects can be found in the literature, and a smaller number of applications can be found in the market. [7] and [8] describe an application in the coffee industry, more cases can be found in the fish industry [9-10], in wine, fresh food and beef [11-12], [13-14], milk, eggs and pasta [10-6] and seafoods [14].As reported in the case studies found in the literature, the application of blockchain technology in the agri-food industry is strictly related to the product and, consequently, to the supply chain. Different products require different information to be stored, different IoT and ICT tools needed to collect this data, and different industrial backgrounds. Thus, each specific industry, like that of ancient grains, requires vertical and focused business and technology models capable of facilitating the implementation of such tools, overcoming the entry barriers of low informatization and digital awareness of workers.

3 Pilot project description

3.1 Pilot project introduction

As mentioned in the previous section, the aim of the pilot project was to analyse the ancient grain supply chain in order to identify the critical points and the information to be exchanged between the different actors.

In order to achieve this result, a case study analysis was carried out within three actors involved in the pasta ancient grain supply chain in the Tuscany region of Italy, namely a farmer, a miller and a pasta maker. The aim of the case study was to understand the production processes, the Critical Control Points (CCP) and the documents exchanged between the different actors, using the Business Process Modelling Notation (BPMN) standards.

Figure 1. Pilot Supply Chain representation.

3.2 Pilot project process and information

In this section, the BPMN diagrams of the supply chain, the CCPs for every considered phase and the data and documents involved are reported. The first actor presented is the farmer, which is the most upstream of the supply chain analyzed within this project, producing ancient wheat. Then the second node of the supply chain is the mill, that deals in turning grain into flour and the last one is the pasta maker, which turn the flour into pasta representing the finished good downstream of the whole supply chain.

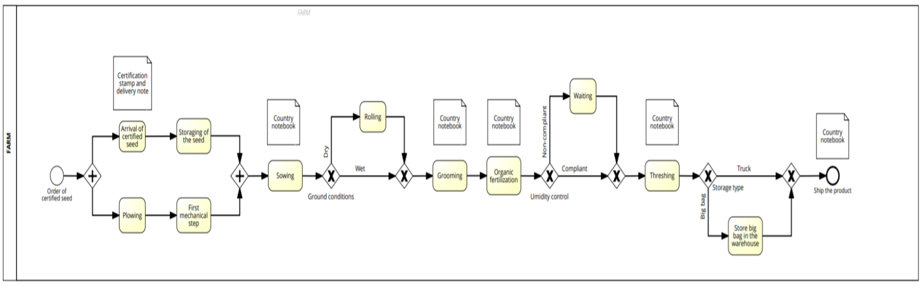


Figure 2: BPMN diagram for farm process

The main activities of the farmer are shown in Figure 2. It specialises in the cultivation of cereals, including ancient wheat. In order to obtain a high quality product, the farm only buys seeds certified by the *Agricultural Consortium of Siena*, founded in 1901 with the aim of supporting agriculture and increasing agricultural production in the area. The process begins with the purchase of the seeds, which require a certification stamp issued by the *Consortium of Siena*. In particular, the seed is certified by CREA, a national research organisation that certifies the authenticity of the variety purchased. This first step is followed by the sowing of the seeds. In the case of ancient wheat varieties, the amount of seed to be sown is around 160-180 kilograms per hectare [kg/ha], as opposed to normal cereals which are sown at 200/250 kilograms per hectare [kg/ha]. This is followed by rolling to compact the soil and improve germination. The sowing, tilling, organic fertilising and threshing phases are recorded in a special register called the *country notebook*: a document that allows farms to record all the operations carried out in the field, the protocols followed and the techniques used. In particular for each phase the main treatments to be reported in the *country notebook* are the name of the crop treated and its extension expressed in hectares, the date of the treatment, the name of the product and the relative quantity used, expressed in kg or litres, the type of adversity that has made the treatment necessary and the dates of the most important phenological stages of each crop: sowing or trans-planting, the beginning of flowering and the harvest.

In the threshing phase thanks to the high digitalization of the combine harvester and the presence of GPS sensors, it is possible to obtain the geolocation of the crop and to record it in the blockchain. Once the grain has been harvested, there are two possible storage ways: the first is the truck where the grain is stored in the trailer and shipped directly to the customer and Big Bag where the grain is stored in containers with a maximum capacity of 1300-1400 kg, and then placed in the warehouse. The Big Bag will then be shipped to the next actor in the supply chain to process the grain into flour.

In summary, for the farmer, the main documents that must be uploaded to the blockchain to ensure food safety, traceability and quality are:

- seed certification;
- country notebook
- field geolocation;
- a document which records some information (quantity and batch number) in order to trace the batch of cereals which leaves the farmer.

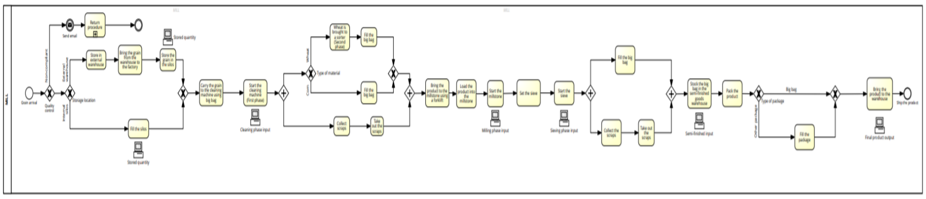


Figure 3: BPMN diagram for mill process

Going forward the supply chain, the second actor is represented by the mil. The main activities of the mill are shown in Figure 3. Specifically, the mill specialises in the production of stone-ground flour. This type of processing produces a flour with an irregular grain size, a higher proportion of bran and complete preservation of the germ. Stone-ground flours are much tastier, more nutritious and easier to digest. The slow and careful processing preserves the nutritional properties without overheating the flours, resulting in a high value final product. The mill buy raw materials by different reliable suppliers. The main raw materials are: soft wheat, cereals, pulses and ancient wheat.

When raw materials arrive, they are accompanied by a transport document containing information such as the document number and date, the quantity and type of raw material and the grain batch number. The incoming raw materials are first subjected to a visual inspection. This is one of the most critical stages in the process. In fact, it often happens that the farmer does not comply with the correct conditions for the storage of the grain, which leads to the detection of non-compliance. The next step is to take a number of samples and send them to a certified laboratory for analysis. If any defects are found, the supplier is immediately contacted and the goods are returned. After the first control point, the raw material can be stored in the silos at the mill warehouse or in an external storage facility.

At this point the production process begins. Almost every day, the production schedule is drawn up. The first phase is the cleaning of the grain. After the silos, the grain is put into big bags. These are then transported to the cleaning machine by forklift truck. After that stage, the product is put back into the big bag and transported to the grinding stone by means of a stacker. It is from this point that the grinding process can be started.

The final stage of the production process is the sieving stage. The product is transferred from the millstone to the sieve by means of an aspiration system. The sieve mesh is set according to the type of flour required. At the same time, the waste from this process is collected. On average, the rejects from this stage are around 15%. In summary, the average scrap of the whole production process, from the cleaning phase to the sieving phase, is about 18-20%. At the end of the transformation process, the flour is returned to the big bags.

Periodically, a test is carried out on the finished product using Chopin's Alveograph to evaluate some technical aspects of the flour, such as the strength, toughness and extensibility of a dough of flour, by plotting the behaviour of a dough of flour on a graph called an alveogram. Before being packaged, the flour is stored for approximately 7-10 days.

At this stage the flour is ready for packaging. Three types of packaging are used: the big bag for sale to large customers, the 25 kg bag and the 10 kg bag. They are stored in the finished product warehouse.

In summary, for the mill, the documents that can be stored into the blockchain are:

- the *mass balance* (that contains information regarding on the input and output of the raw material for that phase);
- the date of arrival of the ancient grain;
- the type and quantity of wheat;
- the number of the transfer document relating to the wheat purchased;
- the processing dates;
- the quantity of wheat obtained and the batch number;
- the scraps and the yield, that can be easily calculated from the ratio output quantity to the input quantity (the *bass balance*).

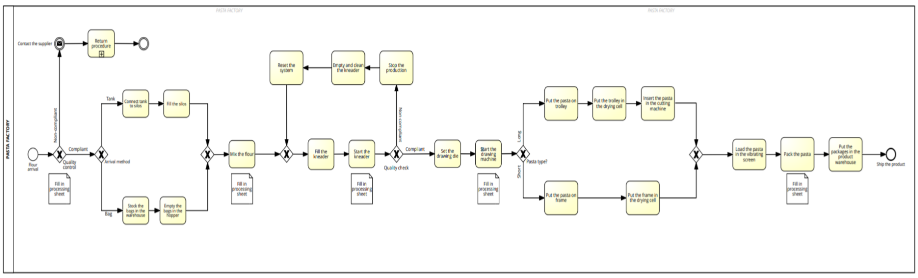


Figure 4: BPMN diagram for pasta maker process.

Finally, the activities of the pasta factory are shown in Figure 4. This actor of the SC is specialised in the production of pasta according to ancient processes and criteria. The production process must be carried out at low temperatures (below 38 degrees Celsius), with the aim of preserving the organoleptic characteristics of the product in order to guarantee a high level of quality and a unique taste. In order to guarantee the high quality of the product, the factory relies exclusively on a portfolio of reliable suppliers. The suppliers are personally selected by the pasta maker, who visits them to assess the quality of the product and the production process.

Prior to ordering, the pasta plant asks its suppliers for raw material samples to perform gluten tests and evaluate the quality of the product. If the test is passed, the factory proceeds to order the raw material. The raw materials arrive with the transport document, which contains some information such as the document number and date, the quantity and type of raw material and the batch number. As soon as the raw materials arrive, they are subjected to documentary control and visual inspection. The initial control phase is critical to detect any non-conformities. If any non-conformities are found, the supplier is immediately contacted, some pictures are sent to them and the goods are returned. In general, the number of non-conformities is low thanks to the strong relationship and trust between the pasta factory and the selected suppliers.

The raw material can arrive in tanks or in bags (25 kg). In the former case, it is sent directly to the silos, which have a capacity of 10 tonnes, while the bags are stored in the warehouse and then manually loaded into the hopper.

This is the point at which the production process is ready for start. The production schedule is set every 15 days and the production lead time is approximately 2 weeks.

The first activity is to mix the flours to obtain the desired type of pasta. The mixture is then sent to a long kneader (4 metres) to start the kneading phase. This phase is the most critical of the whole process, as it is the one in which any non-conformity could be found. This is possible thanks to the expertise of the operator, who can detect anomalies simply by observing the dough. If a non-conformity is detected, it's necessary to stop the line, empty the mixer, discard the dough, pass organic semolina to clean the line to avoid contaminating the following steps, empty the line and restart production.

Then, depending on the type of pasta to be made, the bronze drawing die is set and the drawing process begins. This phase of the production takes about an hour and a half. There are two different ways to store pasta. In particular, long pasta is placed on trolleys, while short pasta is placed on frames. This is followed by the final phase of the production process, the drying process. The trolleys and frames are moved by hand to the drying cells, where they remain for 3-6 days. This is the most important phase of the process, as it requires very long drying times at low temperatures in order to obtain a quality finished product. After this drying period, the long pasta, unlike the short pasta, is cut before being packed.

During the production process, several controls are carried out, such as visual inspection, morphological, temperature, humidity, colour, cutting and drying controls.

Humidity is the most important parameter to control because drying is strongly influenced by humidity. Once the drying process is complete, the finished product passes through the vibrating sieve. After this phase, the pasta is ready to be packed and stored in the warehouse for a minimum of 15 days and a maximum of 6 months. The average waste in the whole process is about 10-20%.

In summary, for the pasta maker, the documents that can be stored into the blockchain are:

- the *mass balance* (that contains information regarding on the input and output of the raw material for that phase);
- the date of arrival of the flour;
- the type and quantity of flour;
- the number of the transfer document relating to the flour purchased;
- the processing dates;

- the quantity of pasta obtained and the batch number;
- the scraps, that can be easily calculated from the the ratio output quantity to the input quantity (the *bass balance*);
- the production process parameters.

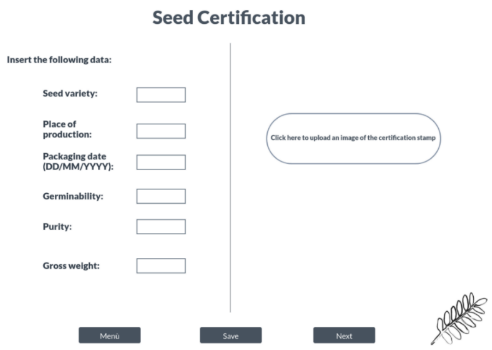
3.3 Pilot project PLM implementation and data management

Starting from the data defined in the previous section, a data model has been defined and a framework for data storage and exchange has been developed, using different commercial software in a product lifecycle management architecture.
As mentioned above, mockups representing the user interfaces where each of the three actors will upload data, information and documents that will subsequently be entered into the blockchain, have been developed.
This section provides some screenshots and a brief description of the mockups. Due to space limitations, only the interface of the first actor, the farm, will be described in detail. First, the user must log in using the ID and password used to register on the platform. Once the user has logged in, the main menu appears on the screen. It contains four items, which represent the documents that must be uploaded to the blockchain in order to guarantee food safety, traceability and quality. In particular, they are: Seed certification, Country notebook, Field geolocation and Transport document.

- **Figure 5: Farmer menu interface.**

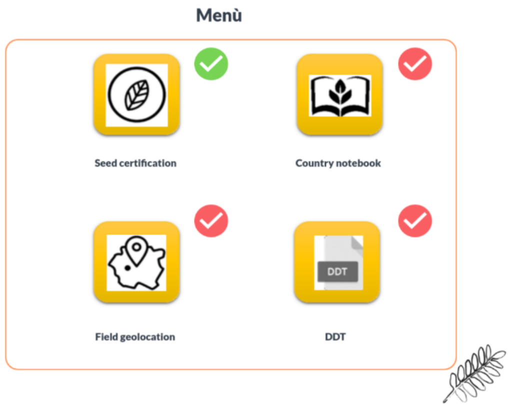
The first document to be uploaded is the seed certificate. This is a document issued by the consortium to the farmer at the time of the sale of the seed, guaranteeing the authenticity of the characteristics of the seed itself. The user has to enter in the platform some information contained in the seed certification stamp (Figure 6), such as

- Seed variety
- Place of production
- Date of packaging
- Germination
- Purity
- Gross weight



- **Figure 6: Farmer seed certification interface.**

Once this part has been completed, the platform returns you to the home screen, in which the item you just completed appears with a green tick, while the remaining missing items appear with a red tick (Figure 7). The user is free to continue with the loading of the missing data.



- **Figure 7: Farmer seed certification interface completed.**

Once the data on the seeds has been acquired, it is transferred to the blockchain linked to the software, without any action by the user and without the possibility of modifying the existing uploaded data. In the same way, the interfaces have been developed until the end of the supply chain.

4 Conclusion and future steps

The purpose of this paper was to present the results of a pilot project implementation of PLM solution based on blockchain technology in the ancient grains Italian Industry. After a review of the application of blockchain in the agri-food industry, a description of the SC has been presented. Due to its peculiarities, the CCP of the three main actors, the farm, the mill and the pasta maker, have been identified and the information data needed to be recorded on a blockchain using specific software have been listed. From a practical point of view, the paper is a useful tool for companies wishing to implement a traceability solution to guarantee food safety and quality. From a scientific point of view, the paper contributes to the definition of a framework for the application of blockchain in the agri-food industry, with a particular focus on the ancient grain sector.

References

1. Srivastava A., Dashora K. (2022), Application of blockchain technology for agrifood supply chain management: a systematic literature review on benefits and challenges, Benchmarking, 29 (10), pp. 3426 – 3442, DOI: 10.1108/BIJ-08-2021-0495
2. Kayikci, Y., Subramanian, N., Dora, M. and Bhatia, M.S. (2020), "Food supply chain in the era of Industry 4.0: blockchain technology implementation opportunities and impediments from the perspective of people, process, performance, and technology", Production Planning and Control, pp. 1-21, doi: 10.1080/09537287.2020.1810757.
3. Saberi, S., Kouhizadeh, M., Sarkis, J. and Shen, L. (2019), "Blockchain technology and its relationships to sustainable supply chain management", International Journal of Production Research, Vol. 57 No. 7, pp. 2117-2135
4. Yadav, S. and Singh, S.P. (2020), "Blockchain critical success factors for sustainable supply chain", Resources, Conservation and Recycling, Vol. 152, 104505.
5. Feng, H., Wang, X., Duan, Y., Zhang, J. and Zhang, X. (2020), "Applying blockchain technology to improve agri-food traceability: a review of development methods, benefits and challenges", Journal of Cleaner Production, Vol. 260, p. 121031.
6. Bumblauskas, D., Mann, A., Dugan, B. and Rittmer, J. (2020), "A blockchain use case in food distribution: do you know where your food has been?", International Journal of Information Management, Vol. 52, p. 102008.
7. Miatton, F., & Amado, L. (2020). Fairness, Transparency and Traceability in the Coffee Value Chain through Blockchain Innovation. 2020 International Conference on Technology and Entrepreneurship - Virtual (ICTE-V), 1-6.
8. Gashema, C. (2021), "Blockchain and certification for more sustainable coffee production – How can blockchain complement the sustainability certifications ."
9. Antonucci, F., Figorilli, S., Costa, C., Pallottino, F., Raso, L., & Menesatti, P. (2019). A Review on blockchain applications in the agri-food sector. Journal of the science of food and agriculture.
10. Westerlund, M., Nene, S., Leminen, S., & Rajahonka, M. (2021). An Exploration of Blockchain-based Traceability in Food Supply Chains: On the Benefits of Distributed Digital Records from Farm to Fork. Technology Innovation Management Review, 11(6), 6-19. https://doi.org/10.22215/timreview/1446
11. Gashema, Christian, 2021. Blockchain and certification for more sustainable coffee Production : how can blockchain complement the sustainability certifications. Second cycle, A2E. Uppsala: SLU, Department of Molecular Sciences
12. Galvez, J.F., Mejuto, J.C. and Simal-Gandara, J. (2018), "Future challenges on the use of blockchain for food traceability analysis", TrAC - Trends in Analytical Chemistry.
13. Patelli, N. and Mandrioli, M. (2020), "Blockchain technology and traceability in the agri-food industry", Journal of Food Science, John Wiley & Sons, Ltd, Vol. 85 No. 11, pp. 3670–3678.
14. Andrew, J. and Kennedy, W. (2019), Food Microbiology and Food Safety Practical Approaches Food Traceability From Binders to Blockchain.