INTEGRATION OF RFID TECHNOLOGY IN AGRICULTURAL TRACEABILITY TO OPTIMIZE CONTROL AND QUALITY OF PRODUCTS

Emili Everz Golombiéski
Postgraduate Program in Applied Computing – Ponta Grossa State University.
Av. Carlos Cavalcanti, 4748.
84030-900 – Ponta Grossa – PR – Brazil.
emilieverz043@gmail.com

Maria Salete Marcon Gomes Vaz
Postgraduate Program in Applied – Ponta Grossa State University.
Av. Carlos Cavalcanti, 4748.
84030-900 – Ponta Grossa – PR – Brazil.
salete@uepg.br

Alaine Margarete Guimarães
Postgraduate Program in Applied – Ponta Grossa State University.
Av. Carlos Cavalcanti, 4748.
84030-900 – Ponta Grossa – PR – Brazil.
alainemg@uepg.br

Abstract

Traceability in the agricultural chain is essential to guarantee the safety and quality of food products. The use of technologies such as Radio Frequency Identification (RFID) presents itself as a solution to improve this process, providing accurate and efficient tracking of products throughout the entire production chain. This study aimed to develop and validate an integrated structure using RFID in the traceability process in the soybean grain production chain. The results of this work included the detailed specification of the stages of the production process, using RFID for tracking and monitoring. The integration of RFID proved to be effective, allowing more accurate and efficient traceability, ensuring compliance with quality standards and industry regulations.

Keywords: Traceability; Agriculture; RFID; Production Chain.

1. Introduction

The traceability of soybeans is important in the food production chain, providing a guarantee of product safety and quality. Soybean cultivation, due to its economic relevance and its wide use in the food industry, requires an efficient traceability system to meet the demands of consumers and regulators.

The ability to trace the origin and journey of soybeans from the field to the end consumer strengthens consumer confidence in food safety and provides producers and distributors with essential tools to monitor and manage quality and compliance throughout the entire process. the production chain. This importance is confirmed due to concerns about issues such as food safety, sustainability and transparency, highlighting the demand for robust and effective traceability systems in the soy industry.

Silva and Rezende (2020) highlighted that the traceability of soybeans strengthens consumer confidence and guarantees the quality of food. Scagliusi et al. (2021) pointed out that efficient traceability contributes to the prevention of fraud and the identification of food safety problems, allowing immediate corrective measures to be taken. Simões et al. (2020) pointed out that the traceability of soybeans is a requirement required by national and international quality regulations and standards.

Toledo et al. (2020) highlighted that the traceability of soybeans is a management tool for producers, facilitating the monitoring of production performance and the identification of opportunities for improvement. Rossato et al. (2021) highlighted the importance of traceability for disease and pest control, allowing an effective and targeted response in the event of outbreaks or epidemics.

Silveira et al. (2023) pointed out that the traceability of soybeans is a tool to promote the traceability of derived products, such as oils and bran, increasing safety and reliability in the production chain.

Nunes et al. (2020) highlighted traceability in the food production chain, to guarantee food safety, product quality and consumer satisfaction. This research established a conceptual basis for understanding the challenges and solutions inherent to traceability in the food production chain.

Cardozo et al. (2019) presents an example of the benefit in using agricultural traceability, if there is a decrease in the protein content in soybeans, agricultural traceability can identify whether the cause was a failure in nutritional management, such as nutrient deficiencies during crop growth. plants, or whether environmental factors, such as unfavorable weather conditions, affect the proper development of the crop.

Agricultural traceability also plays a role in agronomic management. By accurately identifying and recording information throughout the production chain, from planting to harvesting, it is possible to trace the origin of food, ensuring its safety and quality. Agricultural traceability makes it possible to identify possible problems, such as contamination or irregularities, enabling corrective and preventive measures to be taken. In this way, it contributes to food safety, regulatory compliance and consumer confidence.

The integration of RFID technology in this context stands out as a tool to improve the traceability of soybeans, boosting the efficiency and reliability of the process. This technology has been widely explored in traceability, with the aim of improving the quality and safety of these products throughout the production chain.

Based on the demands, the objectives of this article are to analyze the specification of soybean traceability systems, focusing on RFID technologies, developing a structural approach to the soybean traceability process.

2. Materials and Methods

The studies carried out in this work provided a structural specification of traceability based on RFID for the soybean supply chain. To define the requirements, a detailed analysis of the processes involved in the soybean supply chain was carried out, from production to distribution to final consumers, identifying the main demands.

Based on this analysis, the structure was defined, including the ability to identify the origin and history of each batch of grains, monitoring growing and storage conditions, and access to nutritional and quality information.

To document the requirements, document analysis and market research techniques were used. These activities made it possible to obtain aspects about consumer demands and expectations in relation to the structural specification of the RFID-based traceability process.

After documenting the requirements, a validation process was carried out. This step ensures that the requirements describe the demands of the business and users, formally approved.

3. Theoretical Foundation

Radio Frequency Identification - RFID technology, regulated by the ISO/IEC 18000-6:2013 standard, establishes the parameters for communication in the frequency range from 860 to 960 MHz. Although it does not provide a specific definition, this standard establishes the technical requirements and communication protocols for radio frequency identification systems. RFID technology allows batches of soybeans to be individually identified and tracked, using labels or tags, which can be read by RFID readers at different points in the supply chain. Figure 1 discusses the functionality of RFID technology.

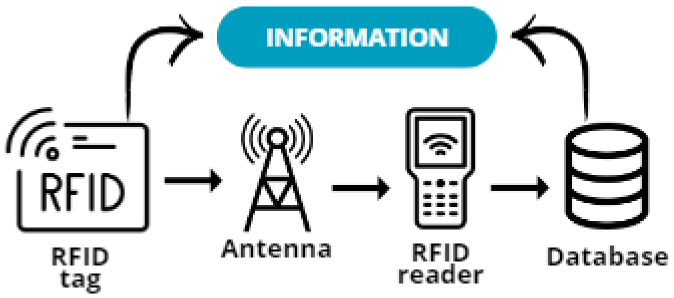

Figure 1. Representation of the information flow with RFID technology.

Johnson et al. (2021) explored the challenges and opportunities associated with using RFID in soybean traceability. The study addressed identification accuracy, systems interoperability and data privacy as critical factors to be considered. The research by Johnson et al. (2021) complements the study by Schmidt et al. (2021), providing information for the use of RFID in the traceability of soybeans.

Zhang et al. (2019) and Chen et al. (2020) highlighted the influence of climatic factors, such as temperature, humidity and atmospheric CO_2, on soy yields and characteristics, affecting the quality of soy presented to the final consumer. Through traceability, it is possible to monitor information such as the origin of the seeds used, the agricultural inputs applied, the management practices adopted, the harvest and storage dates, among other aspects.

Nunes et al. (2020) discussed traceability in the food production chain, highlighting the guarantee of food safety and product quality, highlighting the possibility of identifying possible problems, which could affect the final quality of soybeans.

Defining soybean quality starts from the appropriate choice of seeds. Selecting cultivars with desirable traits, such as high protein, oil or disease resistance, can directly impact the final quality of the beans. Furthermore, agricultural traceability can provide data to identify factors that may compromise quality throughout the production process.

Ferreira et al. (2019) pointed out that agricultural traceability contributes to the implementation of corrective and preventive measures. By identifying critical points that affect soybean quality, producers can make adjustments to their management practices, from seed selection to adequate grain storage, aiming to guarantee product quality.

Agricultural traceability plays an important role in transparency and trust between producers, industries and consumers. Silva and Rezende (2020) addressed the recording and control of information in traceability in the food chain, demonstrating that this information involves the collection, storage and analysis of data inherent to the phases, from production, through processing, distribution and reaching the final consumer.

This information may include data on the origin of inputs, production dates, batch identification, information on transportation and storage, among others. By providing accurate information about the origin and quality of soy, consumers are assured that they are purchasing a safe, high-quality product.

Scagliusi et al. (2021) showed the different aspects involved in agricultural traceability, such as the identification and registration of lots, the collection and storage of information, retroactive and proactive traceability, in addition to the technologies and systems used to implement and manage this process.

Agronomic management is an essential practice to ensure the success of agricultural production, involving various strategies and techniques that aim to improve crop performance and optimize the use of available resources. Among the aspects covered in agronomic management, the importance of efficient use of fertilizers stands out, aiming to meet the nutritional needs of plants and maximize productivity.

Silveira et al. (2023) investigated the influence of different fertilizer management strategies on the productivity and quality of corn crops. The results demonstrated that the appropriate application of fertilizers, considering factors such as dosage, time of application and form of nutrient supply, can generate higher yields and improve grain quality. Furthermore, they emphasized soil and plant analysis to guide fertilizer recommendations, accurately and efficiently.

Chen et al. (2021) highlighted that agricultural traceability can guarantee the quality of soybeans, allowing the monitoring and recording of information throughout the production chain, from planting to the commercialization of the grains. This includes data on agronomic management practices, input use, climatic conditions and processing steps. This information makes it possible to identify and reduce the impacts of weather conditions on grain quality, allowing the adoption of corrective measures and ensuring food safety.

Wang et al. (2022) carried out a review of the impacts of climate change on the quality of soybeans. The study highlighted the importance of understanding the interactions between climatic conditions and agronomic factors in determining grain quality. Furthermore, the need to improve agricultural traceability systems to monitor and control the quality of soybeans in response to climate change is highlighted.

Agricultural traceability in the soybean production chain allows monitoring and reducing the effects of weather conditions on grain quality. The adoption of appropriate agronomic practices, combined with efficient traceability systems, contributes to guaranteeing the quality standards required by national and international markets. This approach strengthens food safety and promotes consumer confidence in the origin and quality of soy products.

Traceability in soybean storage is crucial to guarantee its quality. Technologies such as RFID have been essential in this process, allowing monitoring from planting to grain storage. Studies such as that by Li et al. (2021) and Silva et al. (2023) highlight how RFID facilitates the identification of the origin of grains and storage conditions, contributing to the detection and correction of problems.

RFID has been used for traceability in the soy supply chain, providing control and precision. Lima et al. (2021) and Santos et al. (2020) demonstrated how this system enables the individual identification of batches of grains and real-time monitoring of storage conditions, which directly impacts the quality of the products.

Queiroz et al. (2021) and Morales et al. (2021), emphasized the effectiveness of RFID in improving grain quality throughout the supply chain. The technology offers efficient traceability and contributes to the preservation of quality, assisting in decision-making and controlling food safety.

Rocha et al. (2020) highlighted that RFID technology enables automatic identification and precise tracking of grains, simplifying monitoring throughout the supply chain and ensuring adherence to quality and safety standards.

Rocha et al. (2020), Oliveira et al. (2019), Costa et al. (2021), Silva et al. (2020) e Sousa et al. (2021) realçaram a tecnologia RFID na otimização da rastreabilidade dos grãos de soja. Ao proporcionar identificação automática, rastreamento eficiente e garantia de conformidade com as normas de qualidade e segurança, o RFID fortalece a sustentabilidade da indústria agrícola.

Apesar dos desafios, como a padronização de dados e a interoperabilidade, as pesquisas indicam que o RFID proporciona oportunidades para aprimorar tanto a eficiência operacional quanto a qualidade dos produtos agrícolas. Com a colaboração entre os interessados e os investimentos, a implementação do RFID pode beneficiar toda a cadeia de suprimentos de soja, assegurando a oferta de produtos seguros e de alta qualidade aos consumidores.

4. Results and Discussion

In the context of this research, a structural specification was developed to offer a representation of the soybean production process, covering from the initial planting phase to delivery to the final consumer. This structure was created with the aim of providing a clear and organized understanding of the various steps involved in soybean production, highlighting the application of RFID technologies to improve traceability throughout the production chain.

Initially, fundamental objectives and requirements were established for the development of the structure, aiming to represent the flow of information and activities throughout the soy production chain. These objectives and requirements provided the basis for information collection and analysis and are defined as follows:

- Represent the flow of information and activities throughout the soybean production chain;

- Formally specify the production process, from planting to the final consumer; and
- Include the use of RFID in traceability in the soy production chain.

Based on these guidelines, the development of the structural base involved the following steps. Firstly, the main events and processes that make up the soybean production chain were identified, from planting to the distribution and commercialization phase. These events were mapped, allowing the identification of critical points and opportunities for the application of RFID.

Then, the information flows between the different events were traced, considering data collection through RFID, communication with reading devices and recording of information in a centralized data management system. This flow involved graphical representation, using symbols and directional arrows to indicate the direction of information. Figure 2 illustrates the data that must be inserted into the RFID Tag.

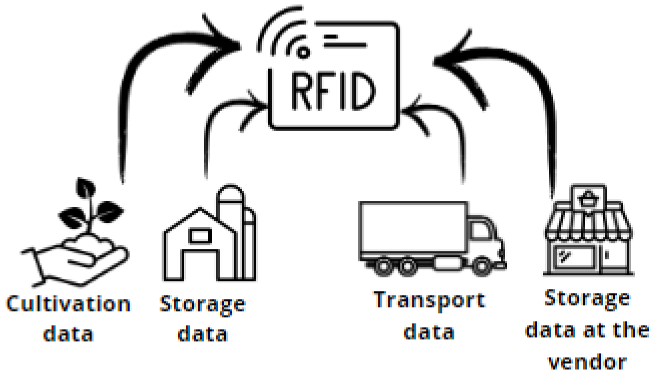

Figure 2. Data stored on the RFID tag.

Furthermore, decision and control points were integrated throughout the traceability process, in which quality assessments are carried out, compliance with current legislation and information inherent to the traceability of soybeans themselves. These points are necessary to guarantee the integrity and safety of products throughout the production chain. In Figure 3, the information collection points by antennas and RFID readers are discussed, where each antenna represents a strategic reading point.

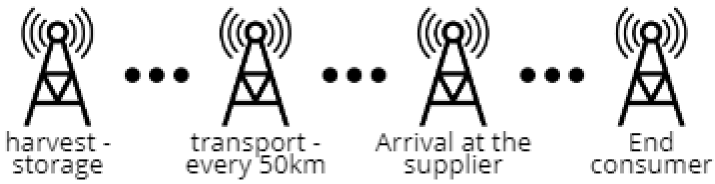

Figure 3. Reading points for the information contained in the RFID Tag.

To ensure the accuracy and completeness of the structural specification, validation methodologies were used that included comparison with field data. This validation guaranteed the representation of the stages and interactions of the soy production chain, providing a clear and accurate view of the process. Validation was conducted in two stages: preliminary review and final verification, each incorporating subsequent feedback and refinements.

Figure 4 illustrates all steps involved in the grain production chain, from initial data collection to final compilation to ensure complete traceability of the process.

Firstly, data collection is carried out through RFID collection points distributed throughout the production chain. These points capture information at different stages, such as planting, harvesting and storing grains. Then, the collected data is connected to the web, allowing integration with external APIs. Variables such as weather conditions, transport routes and geographic locations are analyzed to optimize logistics flow and minimize risks. Finally, all this data, coming from both RFID collection points and external APIs, is compiled and integrated into a centralized system. This system ensures the validity and complete traceability of the production chain, providing a comprehensive and accurate view. With this integration, it is possible to monitor and manage the production chain in a more efficient, transparent and safe way, guaranteeing the quality and conformity of products on the market.

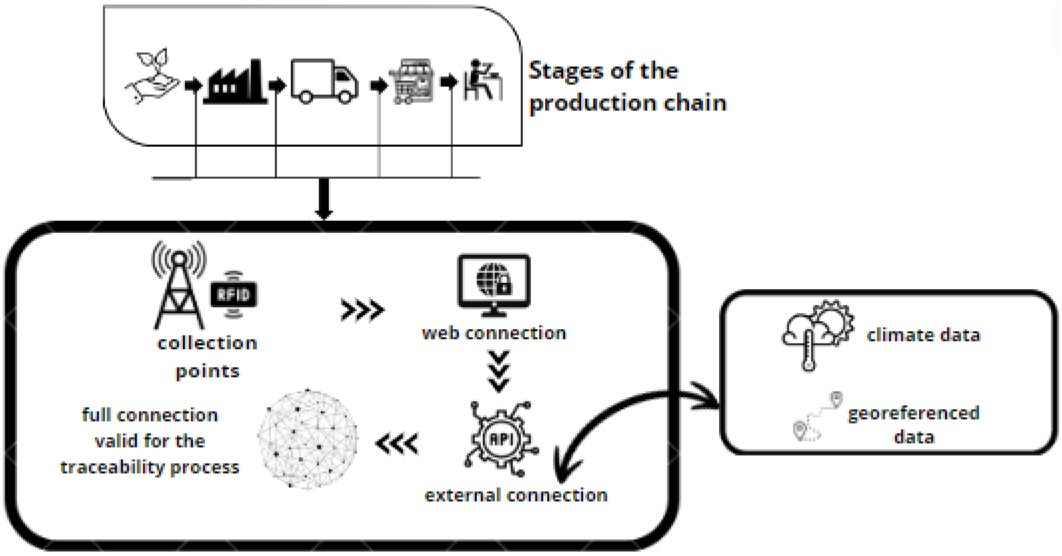

Figure 4. Flow of RFID integration in agricultural traceability.

The first stage of the process is collecting data from the production chain. This phase is fundamental, as it allows the accurate and automated capture of information in real time at all stages of the grain production cycle. RFID collection points distributed throughout the chain record data such as planting dates, cultivation information, harvest dates and locations, storage conditions, among others. This automated collection ensures data accuracy and reliability, eliminating human error and providing a basis for further analysis.

In the second stage, the collected data is connected to a communication network, such as the internet, through devices such as ERBs (Radio Base Stations). This connection enables the integration of collected data with external systems and third-party services. By connecting RFID collection points to the web, it enables remote access to data, allowing real-time monitoring and interventions whenever necessary. Furthermore, this connectivity facilitates the implementation of updates and improvements to data collection and management systems.

The third stage involves the use of APIs to collect climate and georeferenced data, which has an impact on the grain transportation stage. APIs provide accurate information about weather conditions such as temperature, humidity, and weather forecasts, as well as geographic data such as route maps, traffic information, and road conditions. This data optimizes grain transportation, allowing the selection of the most efficient routes, scheduling of deliveries based on favorable weather conditions and minimizing risks associated with adverse events.

Finally, in the fourth stage, all collected and integrated data, both from the production chain and external APIs, are compiled in a traceability environment, integrating the RFID system. This integration provides a comprehensive and detailed view of the entire process, from the origin of the grains to their final destination. With a traceability environment, it is possible to efficiently monitor and manage each stage of the production chain, ensuring the compliance, quality and safety of products throughout their entire journey.

The structural representation facilitated the understanding of processes and provided a basis for making decisions and implementing continuous improvements over time. The application of RFID throughout the soybean production chain has demonstrated effectiveness in improving traceability and reducing human errors, enabling real-time monitoring of production stages. This integration contributed to the optimization of processes, increased operational efficiency and guaranteed product quality, from planting to the final consumer.

Analysis of the data obtained made it possible to identify points for improvement in the production chain. For example, the integration of RFID data with agricultural management systems has revealed inefficiencies in grain transportation and storage, allowing the implementation of specific solutions to reduce losses and improve the quality of the final product. Additionally, the use of RFID helped verify compliance with food safety regulations, providing a detailed and verifiable history of the trajectory of soybeans.

The application of RFID Technology, combined with an effective data management system, demonstrated transparency and efficiency in creating a soy production chain. This approach allowed for accurate traceability of products and provided information for continuous process improvement, increasing the competitiveness of the agricultural sector in the global market.

This research highlights the importance of a well-structured and technologically advanced system for managing the soy production chain. Adopting a formal framework as a visualization and strategic planning tool highlights the need to integrate emerging technologies, such as RFID, into today's agriculture. This integration promotes a more transparent, efficient and safe production chain.

5. Conclusions and Perspectives for Future Research

RFID technology has established itself as a tool to improve the traceability of soybeans in the agricultural supply chain. Its automatic identification and accurate tracking capabilities offer benefits for product quality and safety. However, to obtain the benefits of this technology, it is necessary to develop and validate a formal framework for effective integration of the use of RFID at all stages of the production process.

The structural specification developed in this research is important as a representation and organization of the soybean traceability process, clearly and systematically presenting the various stages of the process. This specification facilitates quick and accurate understanding of interactions between different elements, highlighting decision points, information flows and specific responsibilities, providing a basis for identifying opportunities for improvement and optimization of workflows.

Furthermore, the specification makes it possible to guarantee the consistency and quality of operations throughout the entire soybean production chain. The clarity with which the steps are outlined allows for detailed and continuous analysis, enabling strategic adjustments to increase operational efficiency. This tool proves to be indispensable for managing the production process and also as a means of promoting innovation and the implementation of emerging technologies in the agricultural sector.

An important aspect identified in the research is the need for continuous optimization of RFID systems to reduce costs and increase operational efficiency. This includes exploring new applications, such as environmental monitoring and resource management, that can expand the benefits of RFID in agriculture. The integration of RFID with data analysis technologies can provide information for decision-making and continuous improvement of production processes.

The security and integrity of the data collected through RFID are another point to be considered. Ensuring that data is protected from tampering and unauthorized access is critical to maintaining reliable traceability throughout the supply chain. The implementation of security protocols and the adoption of best practices in data management protects the integrity of information.

For future research, it is necessary to invest in collaboration between producers, researchers and technology developers to accelerate the development of efficient and effective solutions. Furthermore, investing in personnel training to operate and maintain RFID systems maximizes benefits.

The integration of RFID with other technologies, such as the Internet of Things and artificial intelligence, also represents a promising field for future investigations. These technologies can complement RFID, providing a holistic and detailed view of the production process, enabling advanced automation and real-time decision making.

This research highlights the importance of a well-structured and technologically advanced system for managing the soy production chain. The use of visualization and strategic planning tools reinforces the relevance of integrating technologies in agriculture. Promoting a more transparent, efficient and safe production chain increases the competitiveness of the agricultural sector and guarantees the quality and safety of products for the final consumer. Continued efforts in innovation and collaboration are essential to exploit the full potential of RFID technology, ensuring that agricultural production meets quality and efficiency standards.

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