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ORIGINAL ARTICLE

Lean manufacturing in agriculture: benefits, obstacles, and opportunities

Lean manufacturing na agricultura: benefícios, obstáculos e oportunidades

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Abstract: Lean manufacturing (LM) is a management philosophy focused on reducing waste while enhancing system productivity. Although its advancements have been more pronounced in the manufacturing sector, the benefits that LM are increasingly being recognized in other areas, including agriculture. Research on the application of LM in agriculture and livestock farming remains limited but has been gaining traction in recent years, as evidenced by the findings of this study. To contribute to the exploration of this emerging field, this article aims to map the current research landscape through a systematic literature review, supplemented by a content analysis. The SLR presented in this study had three main objectives: to identify which LM tools and techniques are most used in rural production, their benefits, and the elements that are central to their successful implementation. The research identified value stream mapping as the most widely used tool in rural production. The primary benefits observed were waste reduction and increased farm revenue. Successful implementation of LM in this context requires a five-step process, which is detailed in the paper.

Keywords: Lean manufacturing; Value stream mapping; Agricultural production; Farm management; Systematic literature review.

Resumo: O Lean Manufacturing (LM) é uma filosofia de gestão focada na redução de desperdícios enquanto aumenta a produtividade dos sistemas. Embora seus avanços tenham sido mais pronunciados no setor de manufatura, os benefícios do LM estão sendo cada vez mais reconhecidos em outras áreas, incluindo a agricultura. A pesquisa sobre a aplicação do LM na agricultura e na pecuária ainda é limitada, mas vem ganhando força nos últimos anos, conforme evidenciado pelos achados deste estudo. Com o objetivo de contribuir para a exploração deste campo emergente, este artigo visa mapear o panorama atual da pesquisa por meio de uma revisão sistemática da literatura, complementada por uma análise de conteúdo. A RSL apresentada neste estudo teve três objetivos principais: identificar quais ferramentas e técnicas de LM são mais comumente utilizadas na produção rural, avaliar seus benefícios e determinar os elementos-chave necessários para sua implementação bem-sucedida. A pesquisa identificou o mapeamento de fluxo de valor como a ferramenta mais amplamente utilizada na produção rural. Os principais benefícios observados foram a redução de desperdícios e o aumento da receita das propriedades. A implementação bem-sucedida do LM nesse contexto requer um processo em cinco etapas, que é detalhado no artigo.

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Palavras-chave: Lean manufacturing; Mapeamento do fluxo de valor agrícola; Produção agrícola; Gestão agrícola; Revisão sistemática da literatura.

1 Introduction

Agribusiness plays a central role in both the Brazilian and global economies. Its activities involve a wide range of participants who facilitate the transformation and distribution of raw materials from agriculture, forestry, or fishing until they ultimately reach the final consumer. This system, in addition to transformation and distribution agents, is also supported by an intricate network of ancillary players, including technology developers (such as those specializing in packaging, additives, machinery, and equipment) and financial institutions. Within this extensive and sophisticated production system, agriculture and livestock farming hold a pivotal role.

Agriculture has experienced significant productivity increases, largely due to major technological advances. Innovations in terms of agricultural mechanization, biotechnology, and management practices have led to reduced costs and expanded production scales. In this context, “smart farms” are gaining prominence as part of the broader Agribusiness 4.0 movement, which focuses on modernizing the management of agribusiness chain participants through digital means. Indeed, the countryside has seen a surge of startups dedicated to rural management via digital technologies. In 2019, EMBRAPA identified, analyzed, and classified more than 1,200 ag-techs (agricultural-based technology enterprises) operating in Brazil (Dias et al., 2019).

This movement highlights a significant insight: there is a growing recognition among actors in agro-industrial chains, particularly rural producers, of the critical role that management plays in maintaining sustained competitiveness in agriculture. This scenario underscores the potential importance of modern management techniques, such as lean manufacturing (LM), in achieving productive and sustainable agricultural practices. Indeed, LM (Womack & Jones, 2004) demonstrates potential as a model that could assist farmers in enhancing the management of their activities within their supply chains. Applying LM principles could enable, as seen in other productive sectors, improved planning and control of production processes, as well as enhancements in product quality, reduction in production costs, and minimization of losses and waste.

In this way, the aim of this article is to investigate the state of the art in the use of LM tools in agriculture, more specifically in rural production. A Systematic Literature Review (SLR) was used to obtain the results. The SLR had three objectives that contribute to the discussions regarding the use of LM principles in agricultural production. First, it identifies which are the LM tools most used in rural production. This objective allows discussion, as a result, of the potential benefits of these tools. The third objective is to identify the necessary elements and the challenges faced in the use of these tools in rural production. Additionally, the article also takes advantage of all the information gained from the previous studies to propose a research and work agenda that promotes the use of lean manufacturing in agricultural activities.

The article is structured into five sections, including this introduction. The second section provides the theoretical foundation, exploring concepts related to rural production and Lean Manufacturing. The third section outlines the methodology employed in the study. The fourth section presents the results and discussions. Finally, the fifth section offers conclusions and provides suggestions for future research aimed at addressing theoretical and empirical gaps related to the application of Lean Manufacturing in agriculture.

2 Theoretical background

2.1 Rural production and lean manufacturing

Rural production, an important segment of agribusiness, is defined as those activities that explore the productive capacity of the soil by cultivating the land, raising animals, and processing certain agricultural products (Marion, 1999). In contrast to manufacturing, the production of a rural enterprise is strongly subject to biological and edaphoclimatic factors. In this way, the efficiency and effectiveness of its management must necessarily recognize these production idiosyncrasies and incorporate them into its management practices (Breitenbach, 2014). Thus, the use of management tools and methods that have been developed for sectors other than agriculture may require important adaptations. This effort to adapt and develop management tools in line with the particularities of agriculture is an important and promising field of contemporary research. It is in this context that the reflection on the use of the LM in rural production is helpful to evaluate its importance.

A review of the literature identifies several definitions for the term *lean manufacturing* and a set of authors who have applied its concepts in the most varied productive sectors and regions of the globe. Despite the current lack of homogeneity of the concepts that involve the LM philosophy, it is important to highlight that the term *lean* was initially proposed by Womack & Jones (2004). These authors defined it as a strategy or philosophy that promotes the use of a set of tools and practices, such as value stream mapping (VSM), 5S, Kanban, Kaizen, total productive maintenance (TPM), Single Minute Exchange of Die (SMED), cellular layout, Takt Time, Heijunka, and the pulled production system (Abdulmalek & Rajgopal, 2007; Doolen & Hacker, 2005), among others. The use of these tools and practices could reduce waste while improving organizational performance.

LM thinking can be summarized by five principles: value, value chain, value chain flow, pull production, and pursuit of perfection (Calarge et al., 2012; Rodrigues, 2014). These five principles contribute to the elimination or reduction of seven types of waste: overproduction, inventory, waiting, defects, overprocessing, movement, and transportation (Costa et al., 2013; Jones & Womack, 2004; Melton, 2005; Womack & Jones, 2004).

Even though LM emerged in relation to the automotive industry, its application is not limited to this sector. Its potential can be used in other segments, such as agribusiness (Dora et al., 2014). Although the number of LM applications in agriculture and cattle raising is still small when compared to other fields, this does not reduce the potential that LM can bring to rural production. Thus, it is important to know which of the LM tools and techniques have been used in this type of productive system, the difficulties related to this use, and, above all, the benefits that it can bring to rural producers. It is these issues that the next sections deal with.

3 Methodology

A systematic literature review (SLR), as a research method, consists of a way to identify relevant studies on a specific subject, which are evaluated and synthesized according to a predetermined explicit method (Tranfield et al., 2003). This paper adopted the methodology for developing an SLR proposed by Tranfield et al. (2003). The authors divide the review into three stages:

(1) *Planning the Review*: determining the research purpose and protocol.

(2) *Conducting the Review*: searching the literature, selecting studies, assessing quality, extracting data and analysis.

(3) *Documenting the results*: presents the results of the review.

These three phases were essential for conducting this SLR. They have therefore been explained more fully in the research protocol in Table 1.

Table 1. Systematic Literature Review Protocol.

Stages	Objectives	Phases	Steps	How/Where
(I) Planning	Conducting a scoping review to obtain an overview of the subject.	(1) Determination of the objective and research questions.	1.1. Searches in different research sources.	Generic search sources, such as SCOPUS, Web of Science, Scielo and Google Scholar.
			1.2. Delimitation of the constructs and keywords.	Meetings with research field experts.
		(2) Development of a review protocol.	2.1. Definition of the search string, the databases and the selection criteria.	Meetings with research field experts.
(II) Conduction	Research carried out in the selected databases: Scopus, Web of Science and Scielo. Use of Start ® software as a conduction assistance tool.	(3) Studies selection.	3.1. Initial search in the selected databases.	SCOPUS, Web of Science and Scielo.
		(4) Application of the selection criteria.	4.1 Selection by document type.	SCOPUS, Web of Science and Scielo.
			4.2 Selection by language.	
			4.3 Selection by knowledge area.	
		(5) Export of documents.	5.1. Exclusion of duplicate documents.	State of the Art through Systematic Review ® (Start)
		(6) Application of the inclusion criteria.	6.1. Selection of studies that only consider rural production.	State of the Art through Systematic Review ® (Start)
		(7) Application of the selection filters.	7.1. Filter 1: Reading of title, abstract and keywords.	State of the Art through Systematic Review ® (Start)
			7.2. Filter 2: Reading introduction and conclusion.	
			7.3. Filter 3: Complete reading.	
		(8) Data extraction.	8.1. Bibliometric analysis.	Microsoft Excel®.
			8.2. Coding and data extraction.	Microsoft Excel®.
(III) Documents and Results	Reading and analyzing the documents.	(9) Data synthesis.	9.1. Development of an extraction form for each selected article.	Microsoft Excel®.
		(10) Content description.	10.1. Response to research questions.	Microsoft Excel®.
		(11) Making recommendations.	11.1. Identification of limitations and recommendation for further studies.	Meetings with research field experts.

Source: prepared by the authors.

3.1 Stage 1: planning the review

As explained above, Stage I of the SLR process began with the definition of the research question, as well as its objectives, considered critical for its realization and the conduction of all phases. Thus, the SLR of this work sought to answer the following questions, starting from the objective of identifying in the literature the main authors who publish on the subject "Lean Manufacturing (LM) applied to rural production", having as unit of analysis the rural production. Thus, the research questions are as follows:

RQ1. What are the Lean Manufacturing tools and techniques most used in rural production?

RQ2. What are the important elements for the successful implementation of Lean Manufacturing tools and techniques in rural production?

RQ3. What are the potential benefits of using these Lean Manufacturing tools and techniques in rural production?

Examples can be cited of other papers that have also made use of the SRL method to obtain similar results as proposed in this paper. Such is the case of Khorasani et al. (2020); Machado Fagundes da Silva et al. (2022); Psomas (2021); Psomas et al., (2022); Zhang et al. (2021), and Kalaiarasan et al. (2022), which used SRL to gather data that was subsequently used in a further investigation on the issue of interest of each of the studies.

Thus, after defining the research questions and objectives, the constructs and keywords that cover the theme were specified, as well as the search expressions. Based on the chosen constructs, the next steps were to identify the keywords to insert as many relevant terms as possible. This strategy is important to consider the fact that some papers may be overlooked if all relevant synonyms for a concept are not included, since different authors may refer to the same concept using different nomenclatures. The constructs, the keywords and the search expression generated by each can be seen in Table 2.

Table 2. Search term construction.

Constructs	Keywords	Search expression
Rural production	*Agriculture*	("agri*"; "agro*"; "farm*"; "rural"; "smallholder")
	Agribusiness	
	Farming	
	Rural	
	Smallholder	
Lean Production System	*Lean Manufacturing*	(lean AND (manufa*, production, tools, thinking))
	Lean Production	
	Lean Tools	
	Lean Thinking	

Source: prepared by the authors.

Initially, the Web of Science, Scopus, Science Direct, and SciELO were searched to find terms and expressions that could help in the construction of the search strings (scope review). Once the strings were defined, searches were conducted in the Scopus, Web of Science, and SciELO databases. To ensure that the largest number of relevant papers was found, the selection of these databases was made considering their quality as international and national collections.

The search string used in these databases started with common terms from both major fields of study, with the Boolean operator “AND” being added to unite the two major themes of the research, and to limit the number of articles resulting from the search, thus preventing irrelevant content from being analyzed. As a result, the following search terms were used: (“agri*”, “agro*”, “farm*”, “rural” and “smallholder”) AND (lean AND (manufacturing, production, tools, thinking)).

3.2 Stage 2: conducting the review

In the second stage of the SLR, which refers to searches in the selected databases, 1,084 documents distributed over the three databases were identified (Scopus = 660; Web of Science = 420; SciELO = 4). Duplicate articles were excluded using Start® software. This was the first filter of the search. Then, the following selection criteria were applied: (1) only articles from scientific journals; (2) only documents written in Portuguese and/or English; (3) documents without repetition; and (4) articles that talked about the use of LM tools in rural production. Thus, first, 265 duplicate articles were eliminated, and the title, abstract, and keywords of the 819 documents that remained were read and analyzed. This process resulted in 96 articles that were evaluated at a later stage.

To ensure the accuracy of the review process, the next step involved reading and analyzing the introductions and conclusions of these 96 studies. In this context, 51 articles were selected to be read again and analyzed fully. To ensure the quality of the SLR, the full reading of the papers aimed, in addition to eliminating irrelevant articles, to assess the relevance and utility of the studies. Therefore, after completing this phase, 33 articles remained that were accepted for data extraction. The search was completed in January 2022. The retrieval process is presented in Figure 1, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).

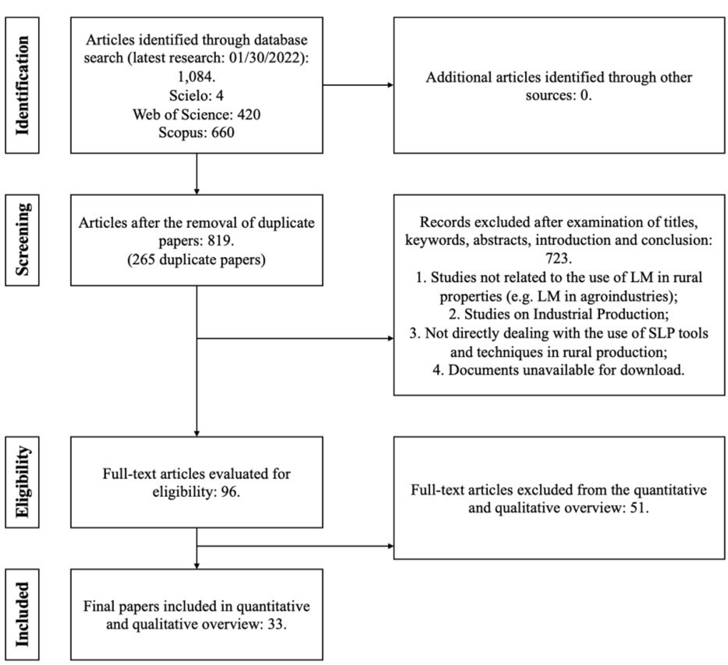

Figure 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).
Source: prepared by the authors.

To ensure the quality of the articles to be analyzed, an inclusion and exclusion criterion was developed. This procedure aimed to assist in the analysis of the documents, thus ensuring that only relevant studies would proceed to the next phase. These criteria can be seen in Table 3 below.

Table 3. Inclusion and exclusion criteria for the literature review.

Criteria	Inclusion	Exclusion
Journal Quality	Scientific journal	Business periodicals, conferences, books, and notes
Access	Complete content written in English or Portuguese	Complete content not written in English or Portuguese
Purpose Alignment	Applying LM tools and techniques in rural production.	Not dealing with the application of LM tools and techniques in rural production.
Unit of Analysis	Rural Production	Industrial Production
Focus	Dealing directly with the use of LM tools and techniques in rural production.	Not dealing directly with the use of LM tools and techniques in rural production.

Source: elaborated by the authors.

3.3 Stage 3: documenting the results

The third stage followed the steps proposed by Tranfield et al. (2003), which focused on the analysis, synthesis, and communication of the results according to this study's three research questions. To achieve this goal, a content analysis methodology was applied, defined by Krippendorff (2018) as a research technique for making replicable and valid inferences from texts (or other significant subjects) to the contexts of their use. The following section aims to present the results of the SLR using content analysis.

4 Results and discussion

4.1 Profile of reviewed articles

First, by analyzing the articles, were possible to observe that more than 78% of the studies were published from 2016, which can be understood as being a topic on the rise, since the trend is growing. Figure 2 presents, in a more visual way, the arrangement of articles by year of publication. The increase in the number of more recent publications indicates that this is a promising theme, but one that still lacks research.

Regarding the journal of publication, the journals Journal of Cleaner Production, Revista ESPACIOS and Computers and Electronics in Agriculture were responsible for publishing 24.24% of the analyzed articles. Only the Journal of Cleaner Production was responsible for 12.12%. The remaining studies are published in several journals, indicating a large number of journals that publish on this subject. Table 4 shows each of the journals, as well as the number of articles published in each.

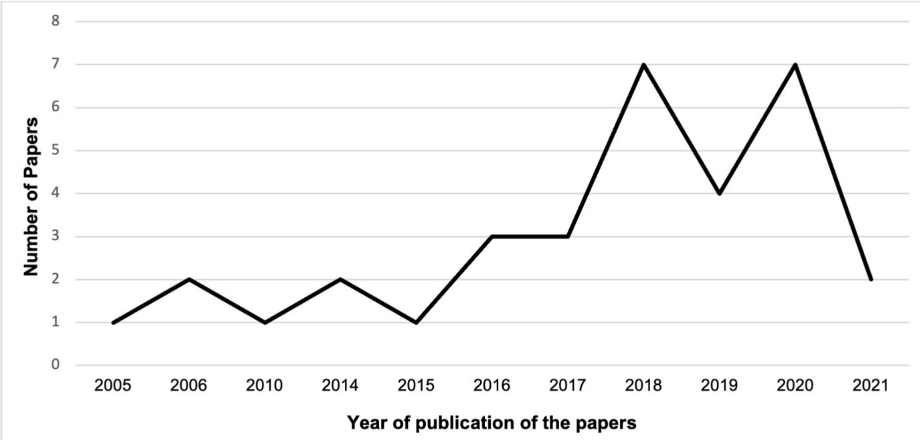

Figure 2. Articles per publication year.
Source: elaborated by the authors.

Table 4. The list of journals considered in the present study.

Journal	No. of articles
Journal of Cleaner Production	4
Revista ESPACIOS	2
Computers and Electronics in Agriculture	2
International Journal of Agricultural Management	1
Quality Engineering	1
Waste Management	1
Systemic Practice and Action Research	1
Journal of Food Engineering	1
Int. J. Agricultural Resources	1
Production Planning & Control	1
International Food and Agribusiness Management Review	1
European Management Journal	1
Int. J. Sustainable Agricultural Management and Informatics	1
International Conference on Information e Communications Tecnologies in Agriculture	1
2015 Proceedings of PICMET '15: Management of the Technology Age	1
Springer International Publishing AG 2018	1
Independent Journal of Management & Production	1
International Journal of Lean Six Sigma	1
Supply Chain Management: An International Journal	1
Journal of the Science of Food and Agriculture	1
British Food Journal	1
Applied Science	1
Agronomy Research	1
Human Interaction, Emerging Technologies and Future Applications	1
International Journal of Advanced Trends in Computer Science and Engineering	1
International Journal Of Scientific & Technology Reserch	1
Int. J. Environment and Waste Management	1
Conference on Manufacturing Systems	1

Source: elaborated by the authors.

Regarding the research methods employed in the articles, the case study method was the most prevalent, appearing in 25 out of the 33 articles, which constitutes approximately 75.75% of the analyzed studies. The remaining papers utilized action research and theoretical/conceptual methods, with two papers each employing these approaches. The survey method was used in only one article. Figure 3 visually illustrates the distribution of each research method across the 33 articles included in this systematic literature review (SLR). Understanding the research methods used in these studies can guide future research by aligning methodological choices with the specific themes being investigated.

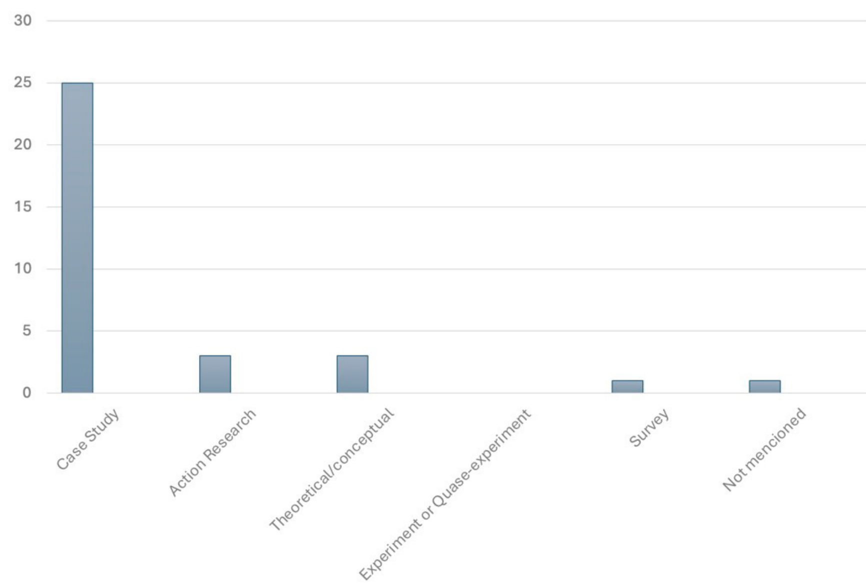

Figure 3. Methodology.
Source: elaborated by the authors.

4.2 Lean manufacturing tools and techniques in rural production

The research revealed that there are several empirical and theoretical initiatives to use LM in rural production. Table 5 summarizes the data found in the SLR. In addition, the table also presents the findings using a technique like 4W1H (Bajaj et al., 2018), which aims to answer basic questions (what, where, when, who and how), in order to describe an event or situation. Although the total number of studies found is relatively modest, considering the importance and contemporaneity of the problem of improving management techniques that enhance food production, it is worth highlighting that 15% of them were conducted in Brazil. Along with the United Kingdom, Brazil is the country that has developed the most research in this area.

About the most used tools of the LM, the analysis of the articles clearly shows that the Value Stream Mapping tool is the most used. Figure 4 presents the tools, which, the VSM is highlighted.

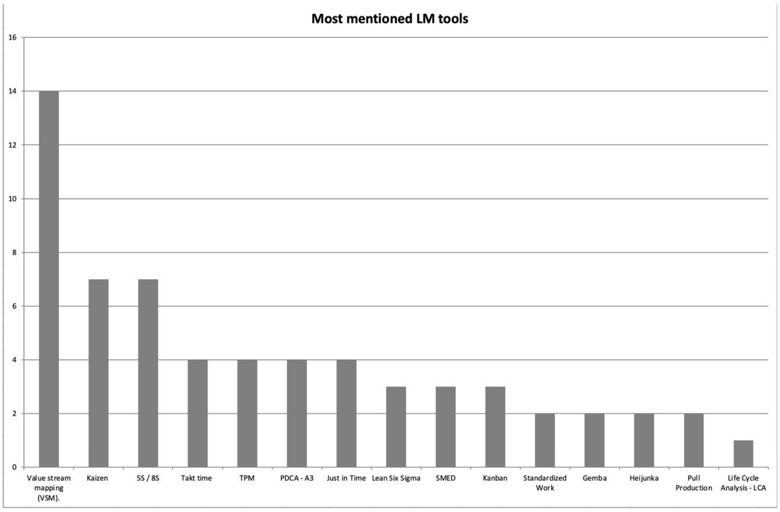

Figure 4. Most used LM tools.
Source: elaborated by the authors.

Table 5. Studies on the use of LM in agriculture and cattle ranching.

Authors	Analyzed Tool	Product analyzed	Research location	Objectives
Cox & Chicksand (2005)	General	Red meat	United Kingdom	Criticism of LM implementation on red meat–producing farms
Taylor (2006)	VSM	Pork meat	United Kingdom	An initial model of an integrated supply chain based on the application of LM principles
Zokaei & Simons (2006)	Takt time (TT); work standardization	Red meat	United Kingdom	Explained the various aspects of LM and reports on the introduction of some practices in various red meat supply chains
Zarei et al. (2011)	Quality function deployment (QFD)	Canned food preparation	Iran	Developed an integrated approach to make the food supply chain leaner
Folinas et al. (2014)	VSM	Corn	Greece	Proposed a systematic approach to measure the environmental performance of LM in food supply chains
Kurtz et al. (2014)	None specifically	None specifically	Brazil	Associated and discussed the differences, and current theoretical streams of LM and knowledge sharing.
Adeyeri & Kanakana (2015)	Lean Six Sigma	Cucumbers	South Africa	Analyzed the need for the use of Lean Six Sigma methodology in problem solving on a cucumber farm
Satolo et al. (2016a)	None specifically	Laying poultry farm	Brazil	Evaluated the LM production system on a laying farm
De Steur et al. (2016)	VSM; 5S; Just in Time (JIT); Kanban	None specifically	Belgium	Presented an SLR about the state-of-the-art of the application of lean practices in the agrifood industry
Satolo et al. (2016b)	Kaizen; TT; work standardization; 5S; TPM; JIT; Lean Six Sigma	Sugarcane	Brazil	Evaluated the use of the LM in a productive unit of the sugarcane agroindustry
Folinas et al. (2017)	VSM	Tomato	Greece	Proposed a systematic approach for measuring the environmental performance of supply chains in canned tomato production, based on LM
Satolo et al. (2017)	VSM; Kaizen; TT; PP; 5S; TPM; JIT; SMED; Lean Six Sigma; Kanban; continuous flow; DMAIC; Poka-Yoke; Jidoka	Sugarcane	Brazil	Conducted case studies in companies from different branches of agribusiness to analyze the degree of adherence to LM, considering the use of techniques and tools and how the specifics of the agribusiness system work

Table 5. Continued…

Authors	Analyzed Tool	Product analyzed	Research location	Objectives
Chen et al. (2018)	The seven kinds of waste	Cauliflower	France	Identification of brokers, artifacts, and knowledge channels to facilitate knowledge mobilization and reduce agrifood waste
Aoki & Katayama (2018)	Heijunka	Baby leaf	Japan	Discussed the implementation of the Heijunka operation in baby leaf production.
Barth & Melin (2018)	VSM; 5S; SMED; TPM; Kaizen; Kanban; pull production; layout; TT; performance management; Heijunka; OEE	Dairy, meat, crops/vegetables	Sweden	Presentation of a framework for LM implementation on Swedish farms
Carson (2018)	General	None specifically	United Kingdom	Examined the Lean Agriculture project in the UK
Lermen et al. (2018)	A3 & PDCA	Fruits	Brazil	Proposed a framework with tools and practices to be implemented throughout lean product development
Melin & Barth (2018)	VSM; PP; 5S; SMED; PDCA; A3	Milk; poultry; meat; grains	Sweden	Presented and tested a framework for lean implementation in the agricultural sector, addressing the challenges from an operational and strategic perspective
Pearce et al. (2018)	Kaizen; TPM; PDCA; Gemba; pull production; continuous flow	Pears and apples	South Africa	Investigated the determinants that drive sustainable performance through the application of lean methods in pear and apple production
Reis et al. (2018)	VSM; Kaizen; JIT; Gemba	Coffee	Colombia	Developed a lean and green synergy (LGS) integration assessment model by formulating a conceptual framework
Liu et al. (2019)	VSM	Food	China	Demonstrated the applicability and suitability of a lean manufacturing system in a food processing plant
Muñoz-Villamizar et al. (2019)	VSM	None specifically	Spain	Analyzed gaps and trends to suggest approaches and methodologies that should be addressed in future studies for implementing lean and green management in the agrifood sector
Caicedo Solano et al. (2019)	None specifically	None specifically	Colombia	Reviewed the application of LM and OR principles in agricultural production and developed a methodology to integrate them and reduce waste
Ufua & Adebayo (2019)	Rick Pictures	Beef meat	Nigeria	Focused on the use of the Rick Pictures tool in parallel with Lean tools.
Caicedo Solano et al. (2020)	None specifically	Bananas	Colombia	Proposed a mathematical model that allows planning of crop maintenance, with the goal of minimizing cost.
Oliveira et al. (2020)	VSM and FIFO	Vegetables	United Kingdom	Applied an established framework for implementing lean methodology to a case study in vegetable production on a vertical farm
Estrada-González et al. (2020)	LCA and VSM	Eggs	Mexico	Aimed to design an eco-efficient approach to egg production on a farm, using LCA and VSM
Andersson et al. (2020)	5S, VSM, fishbone diagram, spaghetti diagram, PDCA, and visualization	Dairy products, eggs, chicken meat, pork, beef, cereals, and gardening.	Sweden	Explored how farmers apply Lean-inspired work processes.
Heng & Mohamed (2020)	*Karakuri* Kaizen	Vegetables	Malaysia	Sought to redesign the typical layout of the vegetable production unit using Karakuri Kaizen lean management principles.
Adawiyah & Istiqomah (2020)	Just-in-time, small lot size, employee involvement, training teamwork, and 5S	Zalacca (salak)	Indonesia	Assessed the motives of SMEs to engage in agribusiness, and the perceived benefits and obstacles associated with adopting lean management; identified the type of quality cost incurred by Zalacca farmers and SMEs; and assesses the most feasible forms of lean practices by farmers

Table 5. Continued…

Authors	Analyzed Tool	Product analyzed	Research location	Objectives
Melin & Barth (2020)	VSM	Milk	Sweden	Aimed to increase understanding about lean implementation where value stream mapping (VSM) is used to create an action plan, on a small dairy and cattle farm in southwest Sweden
Baca-Nomberto et al. (2021)	Kaizen	Rice	Peru	Examined the rice industry, with LM tools to improve quality, increase productivity, reduce inventories, and costs, such as the Kaizen method
Pearce et al. (2021)	None specifically	Fruits	South Africa	Aimed to understand the relationship between lean practice implementation patterns, farm size, and sustainable performance among primary horticultural fruit producers in South Africa

Source: elaborated by the authors.

Table 5, along with Figure 4, reveals that the value stream mapping (VSM) tool is the most widely used in rural production. Cited by several papers (Andersson et al., 2020; Barth & Melin, 2018; Folinas et al., 2014, 2017; Liu et al., 2019; Melin & Barth, 2018, 2020; Muñoz-Villamizar et al., 2019; Oliveira et al., 2020; Reis et al., 2018; De Steur et al., 2016; Taylor, 2006), VSM was the most widely used, by far. One of the possible explanations for the spread of its use in agriculture and cattle raising may be linked to the fact that it is a visual tool that can be easily applied (Folinas et al., 2014), therefore quickly applied and understood by farmers. VSM is also pointed out by Melin & Barth (2020) as an effective way to initiate a culture of collaboration among the members of an organization; in this case, the authors were referring to a dairy farm.

In general, the tool was used as a gateway to utilize the lean philosophy on farms. This can be explained for two reasons. Firstly, the tool offers a visual and easy-to-understand map that provides a very valuable overview of the entire process. With this map it is possible to understand the entire production process and identify all the points of waste. From there, the producer can draw up a plan to improve the process, including, for example, eliminating stages that don't add value to the product and changing the layout when necessary. Secondly, once the points for improvement in the process have been identified, the producer can use other tools to help make the changes. For example, 5S, which can help to organize the work environment, thus reducing work accidents, which are quite common in rural areas. All these aspects help explain why it is such a popular tool.

With seven applications listed, Kaizen Kaizen, or continuous improvement (Baca-Nomberto et al., 2021; Barth & Melin, 2018; Heng & Mohamed, 2020; Pearce et al., 2018; Reis et al., 2018; Satolo et al., 2016a, 2017), with its continuous search for process perfection, was the second most mentioned tool. The authors Baca-Nomberto et al. (2021) pointed out that this methodology allowed the company to reduce waste in rice production by optimizing the resources used, reducing bottlenecks in the processes, and offering some options to use raw materials and transform them into organic pesticides or fungicides. In addition, it also provides indicators that allow better monitoring and control of production. Along with other tools, authors like Barth & Melin (2018), Pearce et al. (2018), Reis et al. (2018) and Satolo et al. (2016b, 2017), Kaizen was also used to reduce waste throughout the production chain studied. Similarly to Baca-Nomberto et al. (2021), Heng & Mohamed (2020) also used kaizen as the exclusive tool. However, unlike Baca-Nomberto et al. (2021), the authors used it to analyse and improve the layout of a vegetable farm. With the use of the tool, the benefits reported by the authors are similar to those cited by Baca-Nomberto et al. (2021), such as reducing waste and employee movement.

About 5S, the tool had a similar quantity of use as Kaizen (Adawiyah & Istiqomah, 2020; Andersson et al., 2020; Barth & Melin, 2018; Melin & Barth, 2020; Satolo et al., 2016b, 2017; De Steur et al., 2016). As can be observed, some articles (Barth & Melin, 2018; Satolo et al., 2016a, b, 2017) used the 5S tool in association with kaizen. This demonstrates that using the tools together can be more advantageous than using them separately. Unanimously, all the articles that used 5S reported significant improvements in the safety of the working environment on farms.

Just-in-time was cited five times (Adawiyah & Istiqomah, 2020; Reis et al., 2018; Satolo et al., 2016b, 2017; De Steur et al., 2016). Adawiyah & Istiqomah's (2020) study concluded that using the tool resulted in benefits such as lower production costs. As can be seen, JIT was cited by some articles that also used other tools in conjunction. In this case, the main purpose of using JIT was to reduce farm stock and optimize the use of inputs, thus achieving better levels of operational efficiency. This shows that the tool can be of great value to farms, since the inputs used in production are often quite expensive.

Takt-time (TT) and work standardization are the two lean techniques discussed in the article by Zokaei & Simons (2006). These tools, according to the authors, is the basis for a continuous production flow, and work standardization. Both are considered a path to continuous process improvement. The first one had four citations (Barth & Melin, 2018; Satolo et al., 2016b, 2017; Zokaei & Simons, 2006), and the second, two (Satolo et al., 2016b; Zokaei & Simons, 2006). Other tool, Total productive maintenance (TPM) was cited by four papers (Barth & Melin, 2018; Pearce et al., 2018; Satolo et al., 2016b, 2017). The tool was used primarily for monitoring machine breakdowns (Barth & Melin, 2018). Also, it was used to visualize service planning, and to educate operators on preventive maintenance work on equipment.

Another well-mentioned tool was PDCA (Andersson et al., 2020; Lermen et al., 2018; Melin & Barth, 2018; Pearce et al., 2018). This tool was used to complement the continuous improvement process. Because it is a very simple and infinite tool, where you end a cycle and start again, it provides several advantages for producers. PDCA can be used in small processes on an individual basis. For example, when applying fertilizer to crops. Employees can rethink the process several times thanks to the methodology of this tool.

Some other tools were also cited in the articles analysed. To compose this discussion section, the most cited tools were decided upon. However, it is worth mentioning a few more: Lean Six Sigma (Adeyeri & Kanakana, 2015; Satolo et al., 2016b, 2017); SMED (Barth & Melin, 2018; Melin & Barth, 2018; Satolo et al., 2017); Kanban (Barth & Melin, 2018; Satolo et al., 2017; De Steur et al., 2016); Gemba (Pearce et al., 2018; Reis et al., 2018); Heijunka (Aoki & Katayama, 2018; Barth & Melin, 2018); Pull Production (Pearce et al., 2018); Life Cycle Analysis (LCA) (Estrada-González et al., 2020) ; Quality function deployment (QFD) (Zarei et al., 2011); and Rick Pictures (Ufua & Adebayo, 2019).

To conclude this section, it is interesting to note that some papers did not mention any specific tool. Instead, these studies analyzed the LM tool generally. Papers like Caicedo Solano et al. (2019, 2020); Cox & Chicksand (2005); Kurtz et al. (2014); Carson (2018); Pearce et al. (2021); and Satolo et al. (2016a) focused their research in understanding how the LM philosophy work out in the agriculture environment. These articles are more technical than practical. In addition, Cox & Chicksand (2005) use examples from the UK red meat market to criticize the use of LM, raising an interesting question about the real benefits of implementing the philosophy in these sorts of companies.

4.3 Implementation and benefits of lean manufacturing

Analyzing the articles, it can be seen that not all of them focus on discussing aspects that could help in the process of implementing LM on farms. However, it is part of this research's effort to shed light on this still little-explored field. For this reason, below is a brief discussion of the papers that explicitly mention suggestions for successful implementation.

Barth & Melin (2018) conducted a project to implement Lean Manufacturing (LM) on farms in Sweden. The project aimed to increase farmers' profitability, resource efficiency, and competitiveness, as well as to support farm growth (Barth & Melin, 2018; Carson, 2018). It was divided into three phases: (i) a pre-implementation phase, followed by (ii) intensive training with “lean coaches,” and ending with (iii) the implementation phase of the tools. The results were deemed satisfactory, as the study reported positive effects associated with increased production efficiency. Most farmers in the program experienced improvements in productivity, product quality, and work environment. In addition to these results, environmental gains were also noted (Barth & Melin, 2018).

The studies by Folinas et al. (2014) and Folinas et al. (2017) proposed the use of the VSM tool in rural production. The objective of both works was to use the VSM to identify sources of activities that did not add value to the processes studied. According to the authors, both initiatives were able to prove positive effects of using VSM in agricultural production, to identify and eliminate waste, and to make production less harmful to the environment.

These effects were also observed in the work of Muñoz-Villamizar et al. (2019). The reported experiences, although few, highlighted that the implementation of LM tools and techniques in rural production should be done in well-planned and defined steps. In this way, it is possible to simplify the process of learning the basic concepts of LM by farm employees and managers. Therefore, the first step is to conduct an analysis and choose the activities that will be included in the process. Next, it would be necessary to present the tools and techniques that would in fact be used and to begin the farmers' training.

In the next step, the actual implementation of the LM tools and techniques must be started. Barth & Melin (2018) stated that LM implementation involves empowering people as they gain knowledge that can be transferred into action. This empowerment involves change — and change is usually difficult. This finding demonstrates how complicated it can be to motivate people enough to get them interested in change, since “change is hard.” But while it is difficult, it also makes it very rewarding, precisely because of the effort that is put into it.

These authors emphasized the importance of “lean coaches” for the success of the process, experts in the area responsible for closely monitoring the implementation of the lean philosophy on the properties. The last step is to evaluate the results obtained and restart the process based on the improvements. One can imagine this last step as having the same objectives as a PDCA cycle, which can also help in continuous improvement.

4.4 Challenges in applying lean manufacturing

The results of the project reported in Barth & Melin's (2018) paper revealed that farmers who reached the end of the LM implementation process reported positive effects on the production structure and work environment. The main positive contribution noted by farmers using the tools was the reduction in time spent searching for tools and materials (use of 5S), increased safety in the workplace, and improvements in waste disposal and recycling routines. It was also noted that an improvement in the work structure increased efficiency in the use of resources. Although the tools and techniques of the LM are managerial, their use also reveals positive environmental effects. Reducing waste as much as possible ends up helping to preserve the environment (Reis et al., 2018).

Zokaei & Simons (2006) used LM in red meat production. The study found that the LM tools and techniques (mainly Takt Time and work standardization) provided positive contributions in most of the production stages. The experiment resulted in savings of 2-3% in the amount spent by each partner in the production chain, in addition to improved product and process quality (Colgan et al., 2013; Liu et al., 2019; Zokaei & Simons, 2006).

The articles by De Steur et al. (2016) and Folinas et al. (2014) showed that VSM has positive impacts on rural production. The former pointed out that there have been improvements in the visibility of the entire value stream and, consequently, a better sharing of information between suppliers and customers. This shared information brought a reduction in food waste and a significant improvement in product quality. The latter argued that VSM is an effective and efficient tool for a series of improvements, not only in waste identification but also sustainability.

However, despite the various benefits that the use of lean tools and techniques can bring to rural production, the application of these methods in the agricultural context faces important obstacles. Cox & Chicksand (2005) advise that interorganizational actions, which are central to some LM tools and techniques, tend to be quite complex in the agricultural sector. This is mostly caused by the family management model that is practiced in most rural enterprises, which makes it difficult for these small producers to communicate with large companies that supply agricultural inputs, for example. This point is corroborated by Simons & Taylor (2007), who stated that the strategic and operational alignment between rural enterprises and other agents of the agro-industrial supply chains (suppliers of inputs, pesticides, etc.) are key issues for the successful implementation of LM.

Another important point is linked to the intrinsic characteristics of agricultural production systems. Unlike what occurs in most manufacturing industries, privileged places for the application of the LM, agricultural production processes are strongly subject to unpredictable events that may entail risks for the predictability and controllability of processes. Classic examples of these risks are those associated with climate or sanitation problems. These singularities of rural production must be considered in the development and implementation of LM tools.

In addition, it should be considered that most agricultural production involves production cycles that are subject to the conditions imposed by its biological character. Despite technological efforts to shorten the production time of agricultural products and smooth the differences in production volumes during harvest and off-season periods, most agricultural production is still subject to less flexible production times and use of resources than those found in various industrial or even service sectors.

Pearce et al. (2021) conducted a study on 132 fruit farms in South Africa to investigate the performance benefits of LM in primary horticultural fruit production. They identified the presence of two distinct groups of producers within the study population. One used LM more intensively, specifically for labor management. This is consistent with the labor-intensive nature of fruit production. According to the authors, this result is comparable to studies dealing with LM practices in service sectors, where labor force management also plays a central role. The authors also identified a relationship between farm size and the benefits of adopting LM practices. The authors stated that the volume of production on the farm was positively related to both the use and results of LM implementation. This study pointed out that the size of the farm is an important determinant for the implementation of some LM practices. This finding is in line with the broader literature that the interaction between organization size and the implementation of LM practices may vary depending on the specific practices being considered. Further, the study concluded that relevant benefits of LM implementation may be insignificant for small farms.

After this analysis of the challenges of using LM tools and techniques in rural production, to conclude this section, an analysis was carried out considering the segment studied in each of the articles. The analysis was based on what Araújo (2018) proposed, which considers three different types of segments. The first of these is called 'before the gate', which is basically made up of suppliers of inputs and services, machinery, implements, pesticides, fertilizers, seeds, etc. In other words, it refers to everything that happens before production on farms. The second refers to what happens 'inside the gate', which encompasses all the activities carried out within agricultural production units. Finally, 'after the gate' comprises activities such as storage, processing, industrialization, packaging, distribution, consumption of food products, etc. The purpose of Figure 5 is to present the classification of these articles in terms of which segment each of the studies refers to.

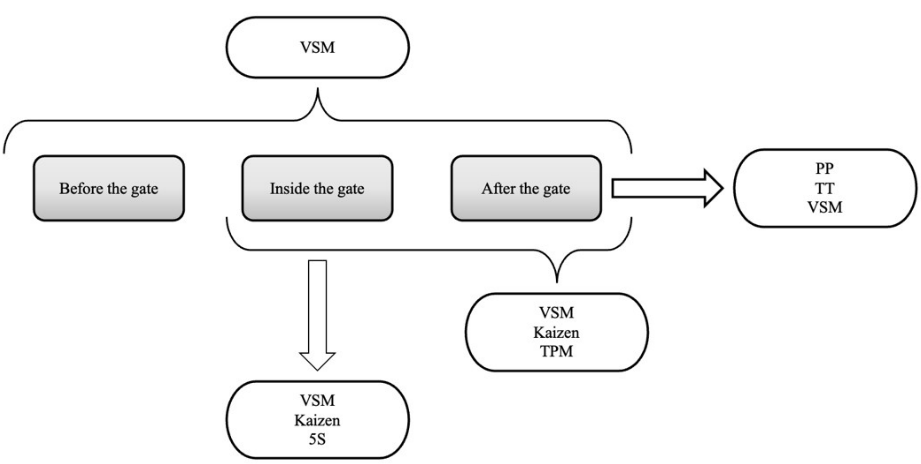

Figure 5. Classification according to the segment studied in each study.
Source: prepared by the authors.

As shown in Figure 5, the VSM tool was used in all segments, and was even the only one to be used 'before the gate'. Considering the types of challenges encountered in the 'inside the gate' and 'after the gate' segments, it is viable to think about the use of tools such as kaizen, 5S, TPM, PP and TT. For example, 'inside the gate' usually faces challenges such as pest control; management planning; machinery use; stock control; pesticide and fertilizer application and others. In these cases, the use of kaizen can help improve production management, management planning, machinery use, etc. 5S can be of great value in helping to organize the work environment, reducing accidents at work, for example. TPM can help with machine and equipment maintenance, thus reducing setup times. PP and TT, on the other hand, are more useful tools for the 'after the gate' segment, as they help to reduce lead times, stocks and handling in agribusinesses, for example. VSM, on the other hand, is a tool that can help in any of the segments, which shows its versatility and ease of use.

4.5 Building a research agenda for the use of LM in agriculture

This section presents suggestions for research that fills theoretical and empirical gaps concerning the application of LM in agriculture, as well as the main suggestions concerning future research alternatives.

A topic that has been gaining attention is the impacts of using LM on the environmental sustainability of farming activities, such as the studies by Barth & Melin (2018), Muñoz-Villamizar et al. (2019), Reis et al. (2018), and Pearce et al. (2021). These point out that the use of LM tools and techniques was beneficial in reducing the environmental impact that farming activities cause. The main benefit found was due to the reduction of waste, mainly materials and resources, used in the analyzed farms.

Another important research topic is the study of how LM implementation and its benefits may vary according to the technological, social, and economic characteristics of agro-industrial chains. For example, Cox & Chicksand (2005) suggest the need to test if the results found in their study are a general rule in food and agriculture supply chains, or unique to the fresh meat supply chain in the UK. According to these authors, the results of LM implementation vary depending on the agent in the agro-industrial chain studied.

The difficulties and benefits of LM implementation may vary according to the institutional environment of the countries or regions where the implementation occurs. This is another relevant research topic regarding LM in agribusiness. Melin & Barth (2018), for example, suggest that there is a need for validation of the framework presented in their study, including the prerequisites for implementing lean production tools, on farms outside the Swedish context. This is also the case for Andersson et al. (2020), who conducted a study on 54 Swedish farms and explored how farmers applied LM-inspired work processes. Although the authors do not suggest the need to include other regions in future studies, it is still crucial to take into account the different characteristics of regions when implementing these LM tools and techniques.

The characteristics of farms, such as size, technological level, etc., and those of farmers (age, gender, education, etc.) seem to affect the LM implementation process. For example, in large farms with a more advanced technological level, the chances of a successful implementation are shown to be higher than in other smaller and/or technologically underdeveloped farms (Melin & Barth, 2018). Studies that prove the relationship of these characteristics to the LM deployment process on farms can provide important research clues.

A further theme observed was related to the realization of theoretical studies that reflect on how the characteristics of agricultural and livestock production impact the mechanisms of LM implementation and benefits. For example, Satolo et al. (2017)

suggest the development of conceptual studies that seek to adapt LM tools and techniques to the specificities of agribusiness production. The authors also suggest a regional mapping of agricultural farms that seek to measure the impact that the use of LM has on these establishments, mainly in relation to profitability gain, market share, customer evaluation, etc.

The study by Caicedo Solano et al. (2020) presented a mathematical model that used LM to plan the use of labor and machinery, operation times, and areas for maintenance, with the objective of minimizing the production costs to farmers. Thus, the authors suggested the inclusion of an analysis that included in the model aspects such as the distances traveled during crop maintenance, a statistical analysis of stocks, and the correlations between climatic conditions and patterns of crop needs in order to maintain product quality.

The literature reports other suggestions for research involving the use of other LM tools and techniques. Melin & Barth (2020), for example, suggest using other LM tools and techniques besides value stream mapping (VSM). Folinas et al. (2014) and Folinas et al. (2017) point out the need to evaluate and possibly improve the VSM tool, adapting its use to food production. It is worth remembering that according to Carrijo (2021), VSM is the lean manufacturing tool most used in agriculture. Oliveira et al. (2020) also mention the need for studies on the use of methodologies such as Kanban and just-in-time in agricultural production. Finally, Liu et al. (2019) suggest future research involving the development of empirical and simulation studies on the use of LM tools and techniques in agriculture.

5 Conclusions

This paper aimed to investigate the state of the art in the use of LM tools in agriculture, more specifically in rural production. A SLR was conducted to obtain the results. The SLR had three objectives that contribute to the discussions: ***RQ1*.** What are the Lean Manufacturing tools and techniques most used in rural production? ***RQ2*.** What are the important elements for the successful implementation of Lean Manufacturing tools and techniques in rural production? ***RQ3.*** What are the potential benefits of using these Lean Manufacturing tools and techniques in rural production?

The systematic literature review (SLR) was an effective approach for identifying the current state of Lean Manufacturing (LM) application in rural production. The articles examined highlighted the primary LM tools utilized in rural settings. The most frequently cited tools included Value Stream Mapping (VSM), Kaizen, 5S, Just-in-Time (JIT), Takt Time, Work Standardization, and Total Productive Maintenance (TPM). Among these, VSM emerged as the most frequently referenced LM tool (RQ1), being mentioned in 14 articles, which accounts for 42.42% of the studies reviewed. Notably, half of these articles focused exclusively on VSM. Kaizen was the second most frequently cited tool, appearing in seven studies, the same number of citations as 5S. Just-in-Time and Takt Time followed, with each being mentioned in four articles.

Concerning the critical elements for the successful implementation of Lean Manufacturing (LM) tools **(RQ2)**, Barth & Melin (2018) propose that the process should be structured into three stages: (i) a pre-implementation phase, (ii) intensive training with 'lean coaches,' and (iii) the actual implementation of the tools. Their findings highlighted positive effects associated with increased production efficiency, with most farmers in the program reporting improvements in productivity, product quality, and the work environment. Additionally, environmental benefits were also noted. As previously mentioned, this model has been corroborated by other studies, which have reported similar positive outcomes (e.g., Carson, 2018; Folinas et al., 2014, 2017; Melin & Barth, 2018, 2020; Muñoz-Villamizar et al., 2019).

Numerous benefits have been identified regarding the use of Lean Manufacturing (LM) tools (RQ3). These benefits include: a reduction in the time spent searching for tools and materials through the implementation of 5S (Barth & Melin 2018); enhanced workplace safety (Reis et al., 2018; Barth & Melin 2018; Melin & Barth, 2020); increased productivity (De Steur et al., 2016; Folinas et al., 2014, 2017); improved waste disposal and recycling routines (Reis et al. 2018); greater visibility of the entire process value stream (De Steur et al., 2016; Folinas et al., 2014, 2017); more efficient resource utilization (Reis et al., 2018); and a reduction in food waste coupled with significant improvements in product quality (Reis et al., 2018; Barth & Melin, 2018; Melin & Barth, 2018, 2020; De Steur et al., 2016; Folinas et al., 2014, 2017). It is noteworthy that the benefits observed in rural production are consistent with those reported in other sectors.

By adopting Lean Manufacturing (LM) tools on their farms, rural producers can achieve several notable benefits that enhance operational efficiency and sustainability. Implementing tools such as 5S can reduce the time spent searching for materials, thus streamlining workflow and improving productivity. Additionally, techniques like Value Stream Mapping (VSM) can provide greater visibility into the entire production process, enabling better planning and resource allocation. The adoption of LM practices also promotes higher safety standards in the workplace and contributes to improved waste management and recycling routines. Moreover, by optimizing processes and reducing waste, farmers can lower production costs and improve product quality, ultimately leading to increased profitability and a more competitive position in the market.

Despite following the research method rigorously, this study still has certain limitations. Firstly, it is important to acknowledge that this is an emerging topic, and new research may soon alter the current understanding. Secondly, although the search strings for the systematic literature review (SLR) were meticulously crafted and the most relevant databases carefully selected, some pertinent articles may not have been identified, either because they did not explicitly use the specified terms or because they were not published in any of the three databases searched. Lastly, the findings presented in this paper are exploratory rather than definitive, serving as a foundation for further investigation by both practitioners and scholars. While LM tools and techniques are not yet fully tailored to the context of rural production, there is substantial evidence supporting their potential benefits in this sector. Nevertheless, significant work remains to be done, and further research is necessary to ensure these tools are effectively adapted to meet the specific needs of rural production.

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Declaration on data availability

The authors declare that all data are available in the article.

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Authors contribution

Pâmella Rodrigues Silva Carrijo worked on the conceptualization, theoretical-methodological approach, theoretical review, data collection, data analysis and writing**. Mário Otávio Batalha** worked on the conceptualization, theoretical-methodological approach, coordination of the data collection, data analysis and writing.