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Review

A Comprehensive Review and Mapping Citrus Supply Chains from a Sustainability Perspective across the European Union, Middle East, and Africa

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Abstract: Citrus fruits are among the most produced and traded agricultural products worldwide, with significant economic and social importance. Despite their importance in the European Union, Middle East, and Africa, the existing literature is limited. Several studies have reviewed different aspects of general agri-food supply chains, but a product-based literature review on citrus supply chains has not been conducted. This paper provides a comprehensive review of the citrus supply chain in these regions, identifying the key research topics, methodologies, and supply chain echelons addressed in the literature. The study employed a systematic review, real-world case studies, and supply chain stakeholders' interviews. This multi-faceted approach allows researchers to highlight research gaps, map a complete citrus supply chain, and provide a detailed material flow and sustainability-oriented overview of potential inputs and outputs at different stages. By incorporating real-world case studies and stakeholder interviews, this paper offers a nuanced and practical perspective on the operational and sustainability challenges unique to the citrus supply chain. This study serves as a guide for future research and enables practitioners to pinpoint areas and strategies for operational improvement across the supply chain.

Keywords: agriculture; citrus; supply chain; mapping; material flow; sustainability; review

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1. Introduction

Agricultural supply chains are the lifeblood of global food security, ensuring that food travels from farm to table efficiently and safely [1,2]. These supply chains involve various entities, including farmers, producers, processors, distributors, retailers, and consumers, as well as the associated infrastructure, logistics, and regulations that facilitate the movement and transformation of agricultural products [3]. This comprehensive process, from planting and harvesting to packaging, transportation, storage, and retailing, plays a crucial role in ensuring the availability, quality, and safety of food for consumers globally. Proper management of these chains can contribute to increasing the export of agricultural products, such as fruits, thereby enhancing countries' foreign currency reserves [1].

One of the most widely grown fruits worldwide is citrus [4], with a global production of around 162 million tons in 2021 [5]. The world's top producers of citrus fruits are China, Brazil, and India [5,6], as shown in Figure 1. The citrus supply chain involves various stakeholders and spans across the globe, with an average trade value of around 98 million metric tons in 2021 [7]. Figure 2 displays the trade value of the top countries exporting citrus fruits in 2021. Citrus fruits, such as lemons, oranges, and grapefruits, are a prominent feature of the Mediterranean region's landscape and culture, and they are a key commodity

in trade relations among the European Union (EU), the Middle East, and Africa. These regions have different roles and interests in the citrus sector, depending on their production, consumption, and export patterns [8,9]. Figure 3 illustrates the top citrus producers in the EU, Middle East, and Africa regions. Spain is the primary citrus supplier to the EU market, while the Middle East and Africa continue to be strategic export markets outside the EU [8,9].

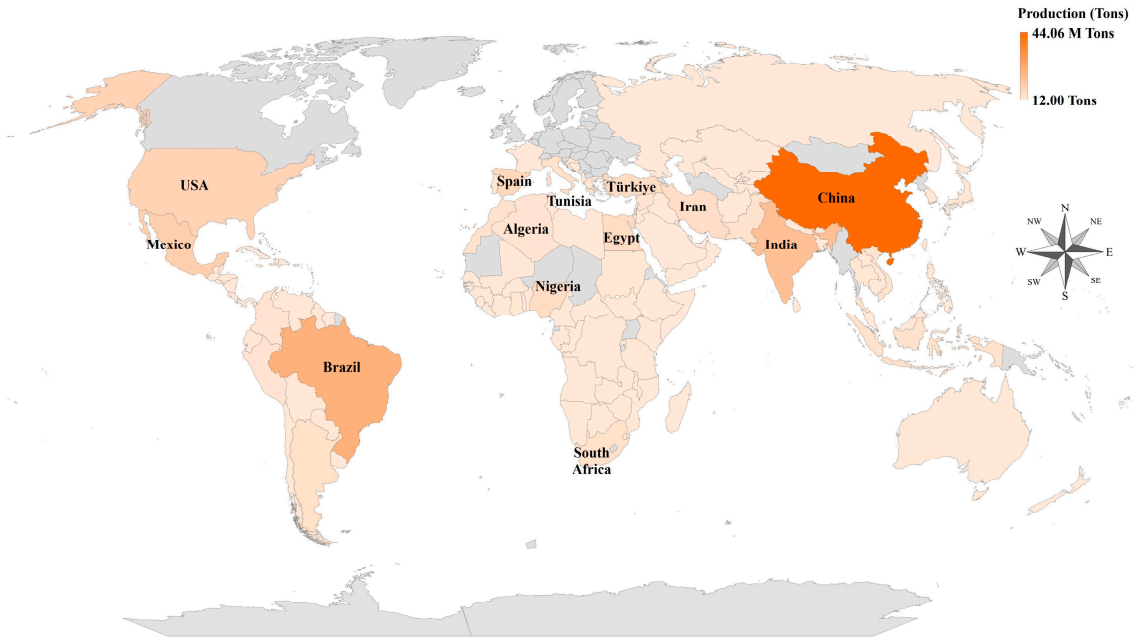

Figure 1. Global citrus production volume (2023) [6].

Despite extensive research on agri-food supply chains (AFSCs), there is a notable lack of product-specific systematic reviews that provide a detailed analysis of a specific AFSC. Previous studies have been conducted on various topics related to the general AFSC. For example, Barbosa performed a bibliometric analysis to examine the development of the AFSC research field [10]. Esposito et al. carried out a systematic literature review on the use of circular economy in AFSCs [11]. Zhong et al. conducted a systematic review of the quality management aspect in AFSCs [12]. Agnusdei and Coluccia systematically reviewed the role of sustainability within AFSCs [13].

Therefore, the main objective of this research is to conduct a systematic literature review (SLR) to investigate the existing literature concerning citrus supply chain management in the European Union, Middle East, and Africa regions. More specifically, this research aims to answer the following key questions:

1. What are the recent research topics in the studied regions?
2. Which research methodology is applied in the research field?
3. Which echelons of the citrus supply chain are studied?

In addition, the data collected from literature and stakeholders' interviews were analyzed to develop a comprehensive understanding of the citrus supply chain structure, flows, and sustainability considerations.

The main contributions of this study are twofold: (1) conduct a comprehensive literature review on studies examining the citrus supply chain, with the aim to identifying areas where further research is needed, and (2) develop and present a holistic supply chain flow map outlining the material flows, inputs, and outputs across the various stages of the citrus supply chain, incorporating sustainability-related considerations. The novelty of this study lies in its precise focus on specific products and regions, combined with the fact that the supply chain flow map is based on a review of the literature and stakeholders' interviews. Through these complementary efforts, this research serves as a foundational reference to

guide future academic investigations within the citrus supply chain domain. Furthermore, the study's outputs are anticipated to enable industry practitioners to pinpoint specific operational areas and strategies for improvement across the supply chain network.

The remaining sections of the paper are organized as follows. The next section illustrates citrus production and exports in the European Union, Middle East, and Africa regions, indicating the importance of citrus in these regions. Section 3 describes the review methodology conducted in this study. Section 4 presents the results of the bibliometric analysis. Section 5 reveals the content analysis results of the reviewed papers, addressing research topics, methodologies, and supply chain echelons. Section 6 illustrates the citrus supply chain structure and flow, along with a sustainability perspective map of the different supply chain stages. Finally, the current work is summarized, and the research gaps in the literature are highlighted in Section 7.

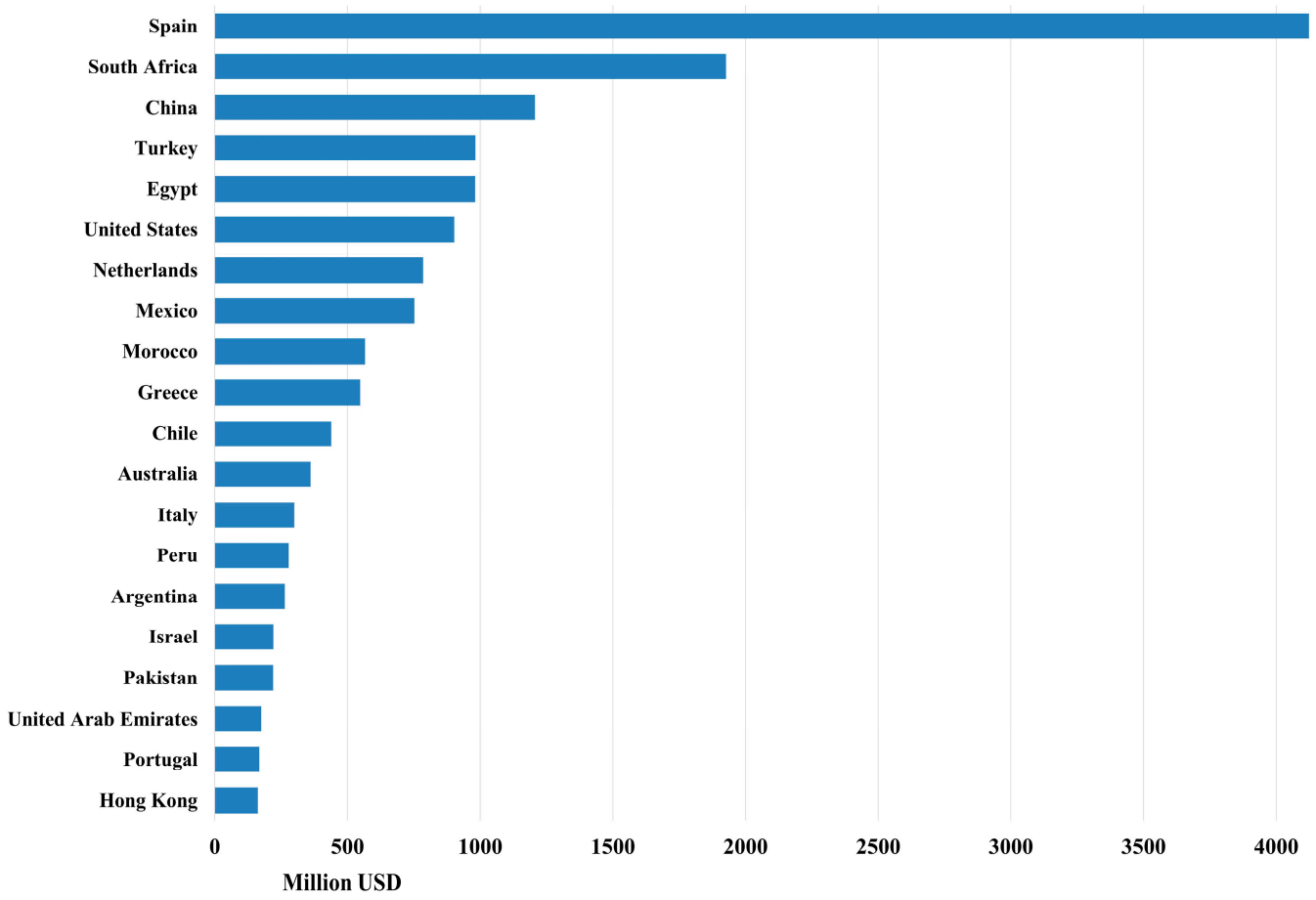

Figure 2. Top global exporters of citrus fruits by trade value in 2021 [14].

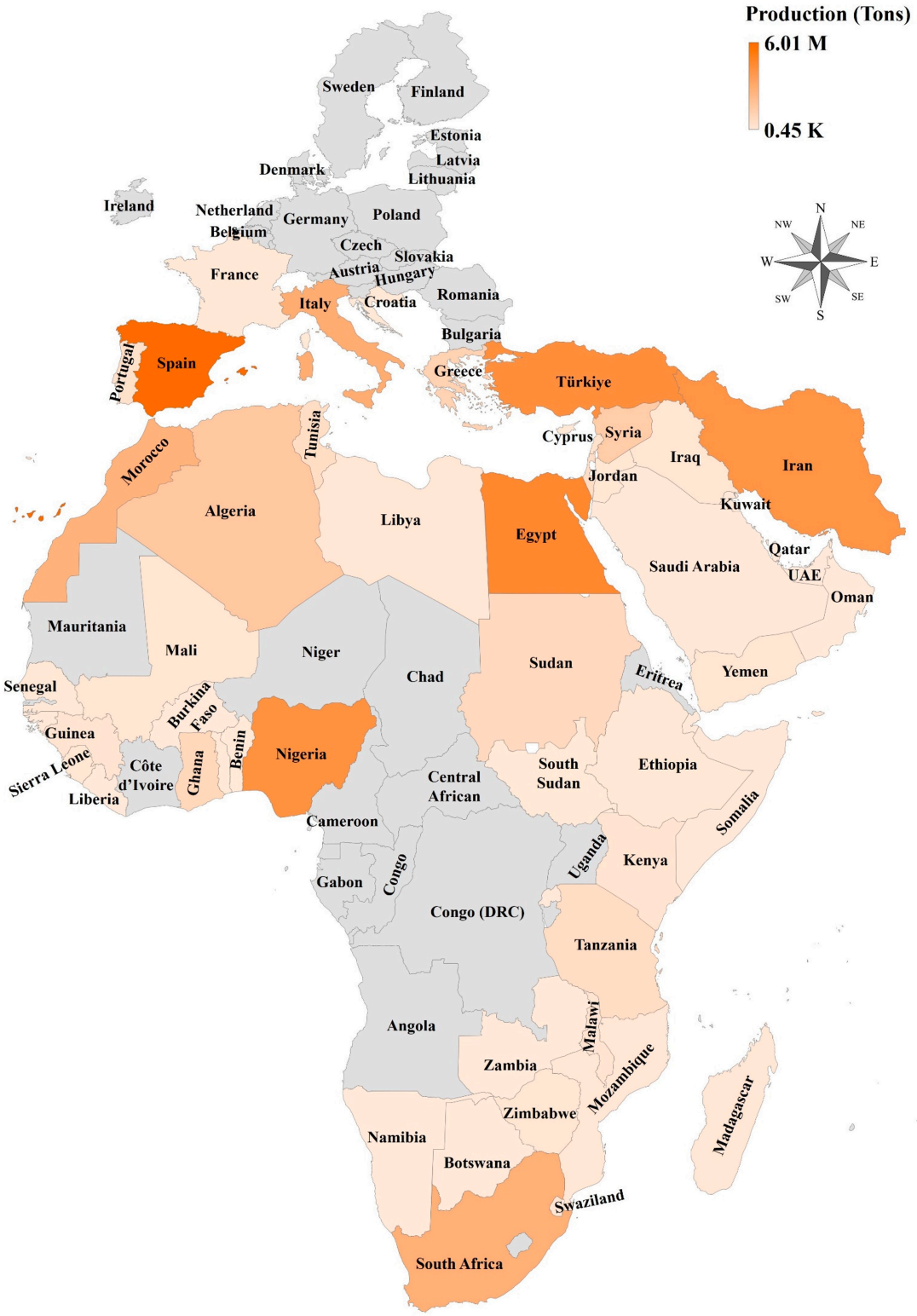

Figure 3. Citrus production in European Union, Middle East, and Africa (2023) [6].

2. Citrus Production and Exports in European Union, Middle East, and Africa

2.1. European Union

The European Union (EU) is a significant player in the citrus fruit industry, with a total production of 11.48 million metric tons in 2021 [15] and a trade value of approximately USD 6.01 billion. Citrus fruits were the second most produced fruit in Europe in 2022 [16].

Spain and Italy are the top producers, with Spain's production exceeding 6 million tons [6] and an export value of over USD 4.1 billion in 2021 [14]. Italy's exports were valued at nearly USD 300 million [14]. The Netherlands, Greece, and Portugal also play key roles in exports, with values of USD 785.1 million, USD 547.7 million, and USD 168.0 million, respectively [14]. Spain's dominance in production and exports solidifies its status as a global leader. Figure 4 illustrates citrus production in the EU, while Figure 5 provides a comprehensive perspective on the export dynamics within the EU from 2011 to 2021, highlighting Spain's leading position.

Figure 4. Citrus production in the European Union (2023) [6].

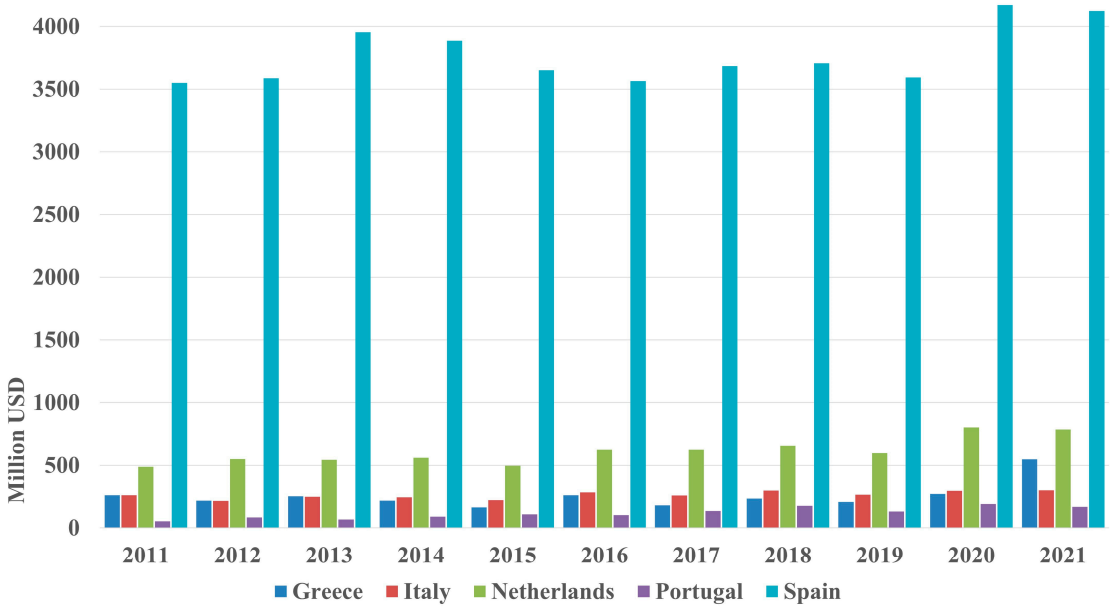

Figure 5. Top citrus exporters from the European Union from 2011 to 2021 [14].

2.2. Middle East

The Middle East is a crucial region in the global citrus market, with Egypt, Turkey, and Iran as key players. Egypt produced 4.64 million tons of citrus in 2021 [6], with an export value of USD 981.6 million. Turkey's production was 4.3 million tons [6], with an export value of USD 981.6 million [14]. Iran produced over 4 million tons, showcasing its agricultural capacity [6].

Figures 6 and 7 underscore the region's importance in global agriculture and trade. Figure 6 shows citrus production in Middle Eastern countries, while Figure 7 illustrates the export values of the top five exporters in the region from 2011 to 2021. Egypt has seen the greatest increase in trade value, while Turkey remains the largest exporter, primarily to Russia.

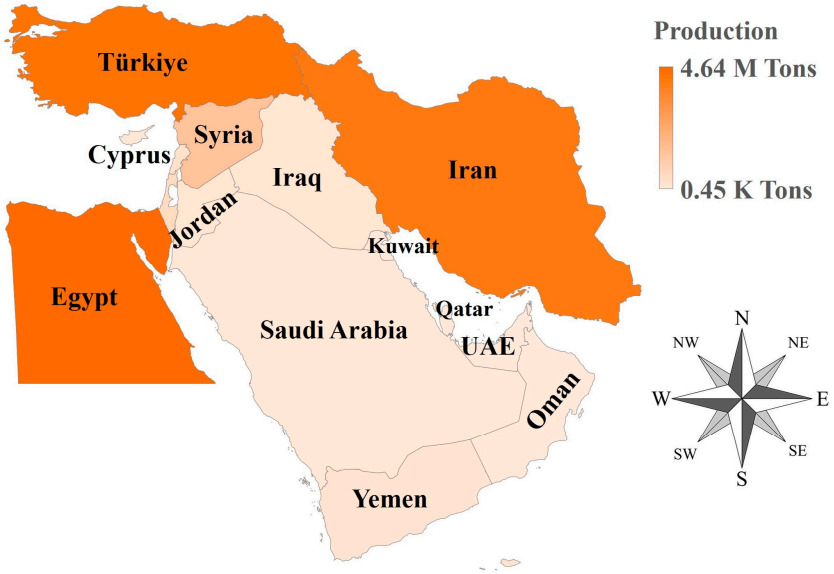

Figure 6. Citrus production in the Middle East (2023) [6].

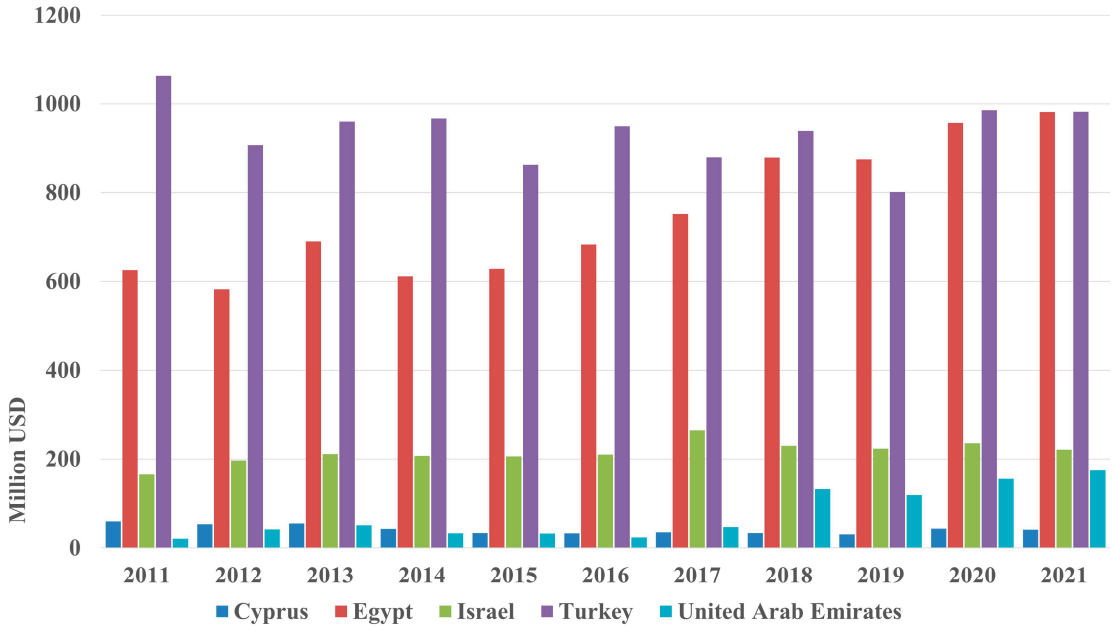

Figure 7. Middle East leading exporting countries from 2011 to 2021 [14].

2.3. Africa

Africa's citrus industry is growing, with Egypt, Nigeria, South Africa, and Morocco as standout performers. Egypt leads with 4.64 million tons of production [6] and an export value of USD 981.6 million in 2021 [14]. Nigeria produced around 20.16 million tons in 2023 [14]. South Africa is a dominant exporter, contributing over USD 1.9 billion in 2021 [17]. Morocco produced over 2.6 million tons with an export value of USD 566 million [7]. Tunisia, though producing smaller amounts, had an export value of nearly USD 13 million [18]. Figure 8 illustrates citrus production in Africa, while Figure 9 highlights the export evolution in Africa from 2011 to 2021, showcasing the consistent performance of Egypt and the growth of Morocco and South Africa. South Africa exports mainly to Europe and Asia, supported by industry associations such as the Citrus Growers' Association and the Perishable Products Export Control Board. These associations facilitate trade, inspect products, and manage export regulations [19]. Interviews with Egyptian stakeholders revealed a need for similar organizations in Egypt to introduce sustainable technologies and policies, standardize practices, and increase exports.

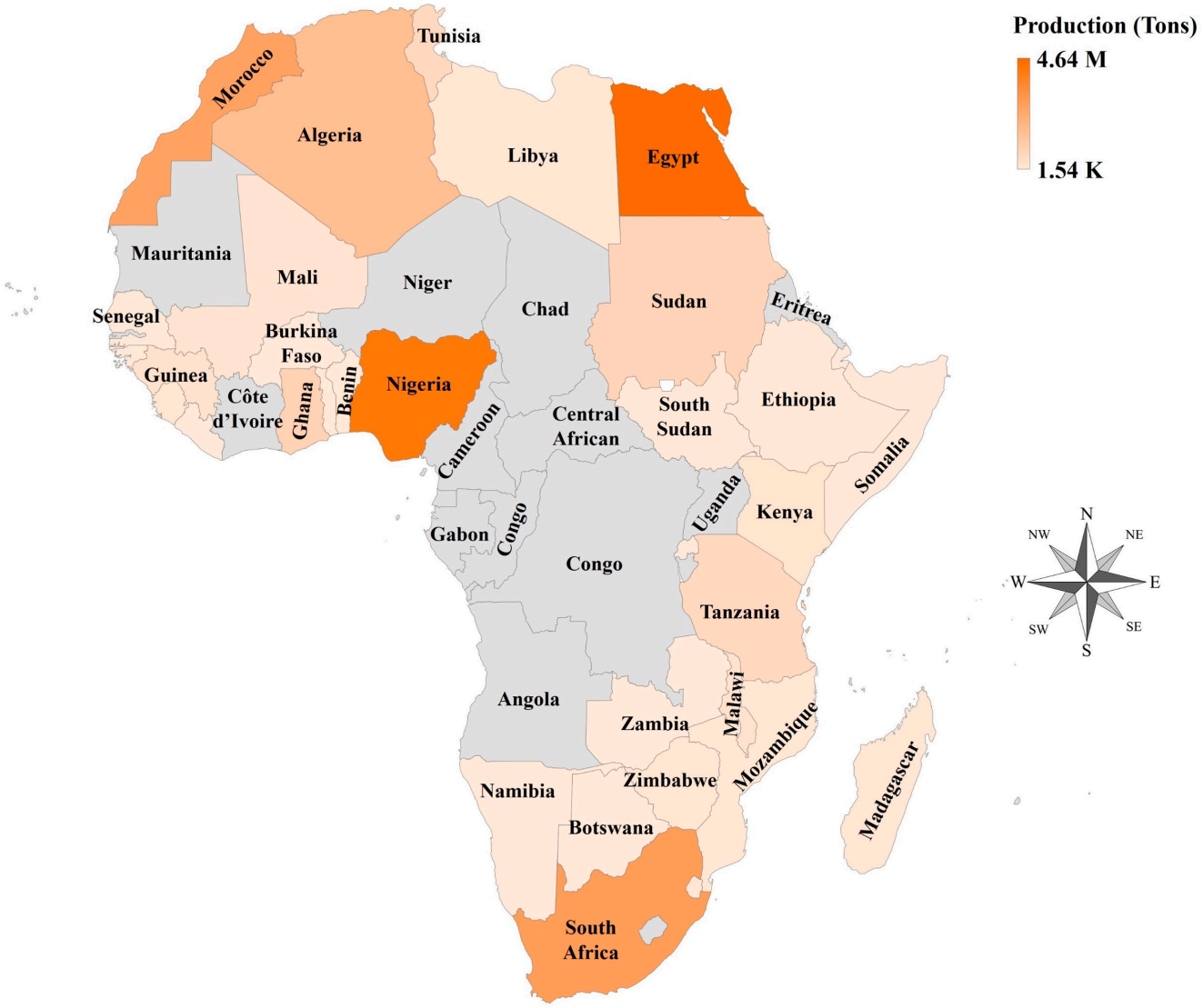

Figure 8. Citrus production in Africa (2023) [6].

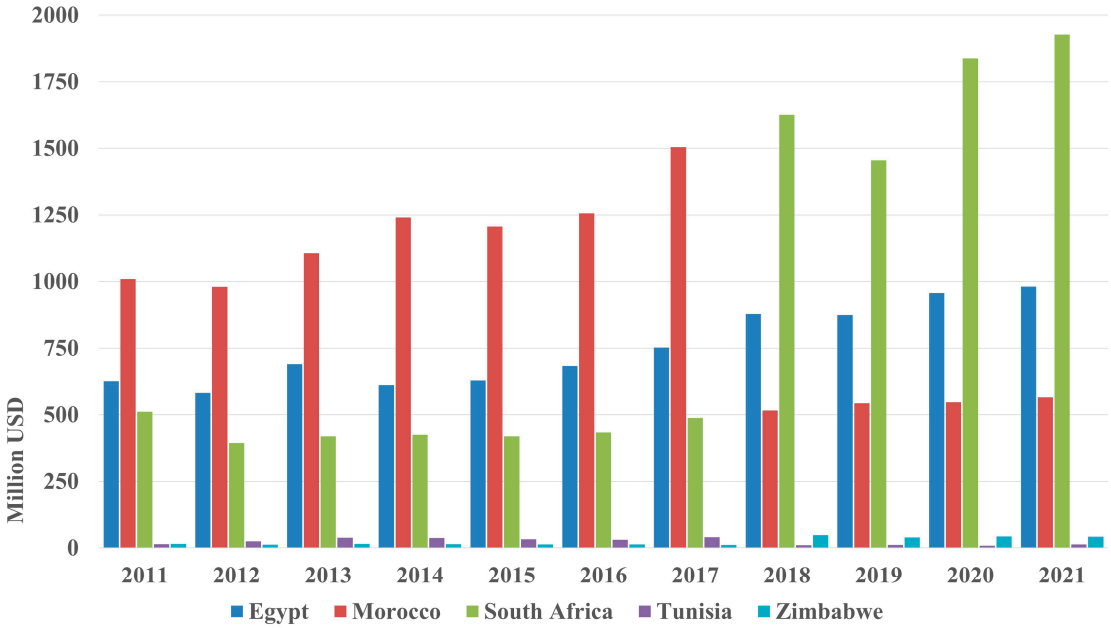

Figure 9. Top citrus exporters in Africa from 2011 to 2021 [14,17,18].

3. Methodology

The primary objective of this study is to review the literature on the citrus supply chain in the European Union, Middle East, and Africa regions. The methodology employed for this study is a systematic literature review, as illustrated in Figure 10. To address the research questions, a comprehensive search was conducted using the databases Web of Science, Scopus, and ScienceDirect. The search terms used were "citrus supply chain" and "citrus supply chain management". The search was restricted to publications in English, published between 2016 and 2023, and was conducted in August 2023, yielding 174 publications.

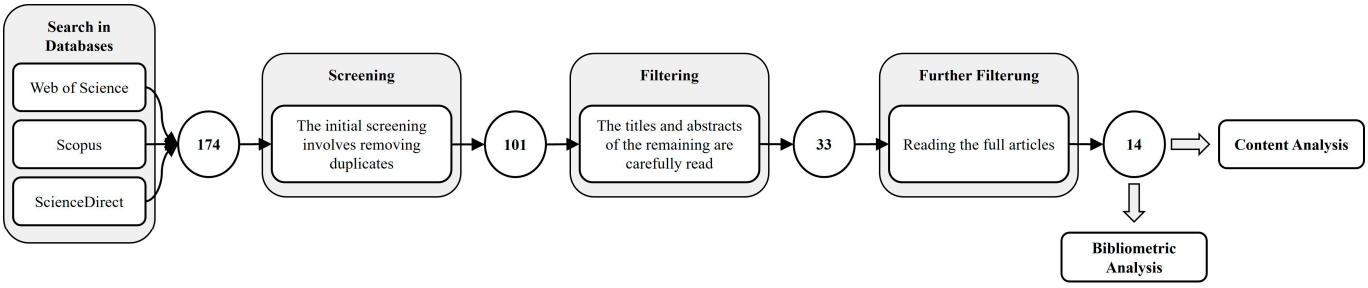

Figure 10. Systematic review filtering and analysis process.

The initial screening involved removing duplicates and irrelevant publications, reducing the number of publications to 101. Titles and abstracts were carefully read to exclude irrelevant studies, resulting in 33 papers. Further filtering involved a full-text review of each paper to exclude those not pertinent to the research objectives, culminating in a final selection of 14 publications.

A bibliometric analysis was performed on the remaining 14 papers, examining the frequency distribution of papers, the distribution of studied geographical regions, and the frequency of countries addressed. Additionally, an analysis of keyword co-occurrence using VOSviewer was conducted.

Subsequently, a content analysis was undertaken to identify the research topics, methodologies, and supply chain echelons addressed in the selected papers. Following these analyses, a comprehensive citrus supply chain flow diagram was developed,

detailing the various product flows within the supply chain. Furthermore, the potential inputs and outputs of the different supply chain stages were illustrated from both material flow and sustainability perspectives.

4. Bibliometric Analysis Results

The annual frequency of the 14 reviewed papers is illustrated in Figure 11. The number of papers increased in 2020, likely due to the disruptions and economic effects of COVID-19. The continued increase in subsequent years indicates a growing interest in this research field.

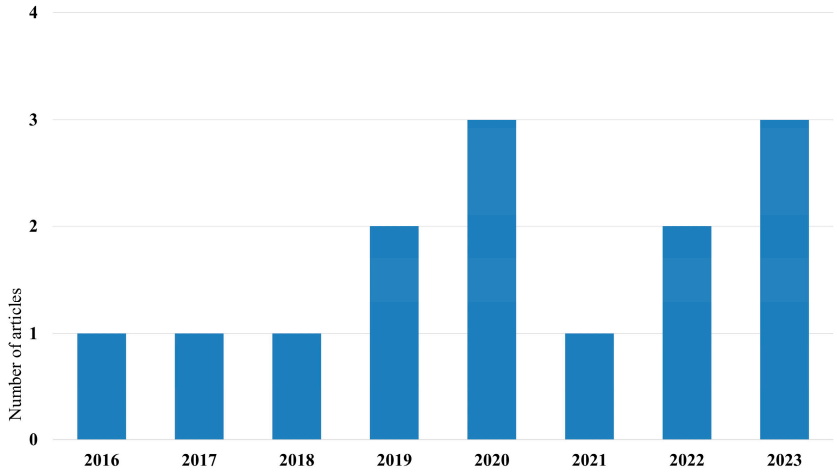

Figure 11. Annual frequency of reviewed papers.

The distribution of studied geographical regions in the reviewed papers is shown in Figure 12. There is a notable scarcity of research in Africa and the European Union compared to the Middle East, despite the significant role of citrus in Africa in terms of production and trade and in the European Union in terms of imports and trade.

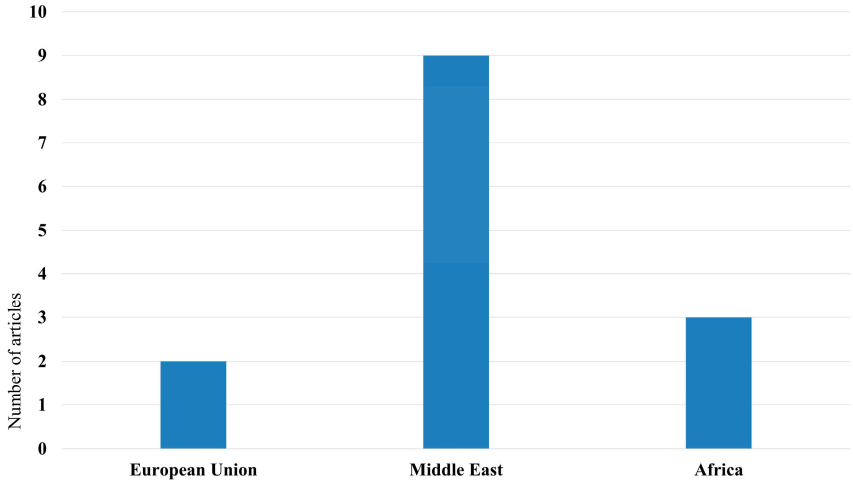

Figure 12. Geographical distribution of reviewed papers.

Figure 13 highlights the frequency of countries addressed in the reviewed papers. Iran has the highest number of research works in the field, despite being the third-largest citrus producer in the Middle East. Notably, there is an absence of research related to Egypt and Turkey, despite them being the top citrus producers in the region.

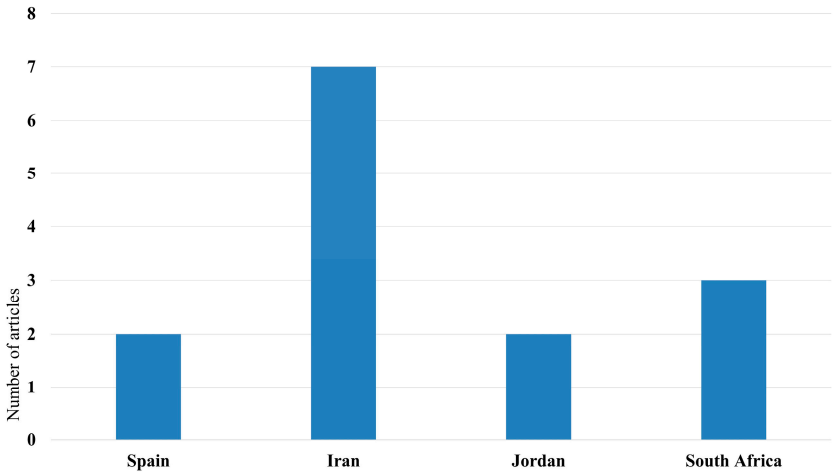

Figure 13. Frequency of countries addressed in reviewed papers.

Regarding the keywords used in the papers, 62 keywords were identified, with 10 occurring at least twice. In total, 2 of these keywords were excluded from the analysis, as they were part of the search string. The most frequent keywords are CO_2 emissions, sustainability, and reverse logistics. The network visualization of keyword co-occurrence is presented in Figure 14. Each node represents a keyword, and the lines indicate connections between them. The size of the node reflects the frequency of occurrence, while the thickness of the lines indicates the frequency of co-occurrence. The keywords are clustered into three groups: sustainability aspects and meta-heuristics (red), reverse logistics (blue), and order-promising process (green).

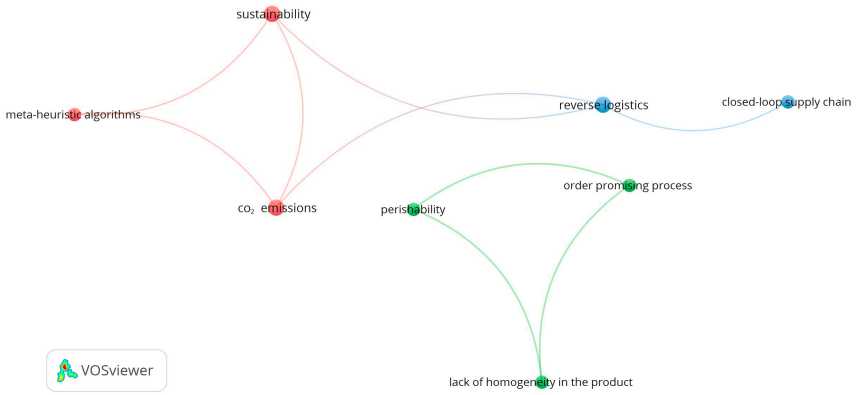

Figure 14. Network visualization of keyword co-occurrence.

5. Content Analysis Results

5.1. Research Topics

The present literature review focused on synthesizing the key research topics addressed within the extant body of work on the citrus supply chain in the European Union, Middle East, and Africa regions. Four primary topical areas are identified that have received substantial research attention: facility location and allocation, cold chain management, order-promising processes, and pre-harvest best practices.

More than half of the papers (57%) addressed facility location and allocation, likely due to the importance of supply chain network design in reducing costs. The ordering process was only discussed in Europe, probably because Europe imports large quantities of citrus, while cold chain management was a concern only in Africa due to the high volume of exports. Pre-harvest practices were mentioned only in the Middle East, likely due to the large amount of land available for fruit production and the expected problems of fruit losses.

Beyond these dominant themes, the review also identified a range of topics addressed across citrus supply chain research. As illustrated in Table 1, sustainability considerations, particularly along the economic and environmental dimensions, represented a noticeable focus. The economic pillar appeared in 78% of the reviewed papers, followed by the environmental pillar. Conversely, the social sustainability pillar received relatively limited attention, featuring in just two of the reviewed studies.

Other infrequently explored topics included resource utilization (e.g., land, water), packaging waste circularity, and the time factor. These topics are of high importance due to global problems of resource scarcity and the environmental impact of plastic waste disposal. Notably, environmental topics, such as waste/residuals, circularity, and CO_2 emissions, were only addressed in Middle Eastern papers. Traceability, quality, and pricing were not discussed in Middle Eastern research, while in Africa, only traceability was addressed in studies on cold chain performance.

To reduce food losses, fresh produce must have an effective post-harvest cold chain to maintain its quality and increase its shelf life. Defraeye et al. proposed monitoring several parameters along the cold chain for the integrated evaluation of cold chain performance [20]. They applied their approach to assess different cooling strategies for exported citrus fruits in refrigerated containers. Goedhals-Gerber and Khumalo investigated the potential causes of temperature variation along the citrus export cold chain from South Africa to the USA, aiming to identify improvement areas for better management [21]. Khumalo et al. focused on monitoring the exported citrus fruit temperature during transit, comparing cellular temperature loggers with conventional ones to improve product visibility in South Africa's citrus cold chain [22].

Product quality and traceability of shelf-life were addressed by Grillo et al., who proposed a mathematical model to support the order-promising process for the fruit supply chain, fulfilling customer requirements in terms of due dates, quantities, homogeneity (sub-types), freshness, and selling price based on freshness [23]. Grillo et al. further applied two concepts in the order-promising process for perishables, linking the product's price with an ageing function and using possibilistic variables to model non-homogeneity in the product [24].

Two publications discussed reducing citrus loss and waste. Alzubi and Noche proposed a new citrus supply chain structure in Jordan, introducing collection points and citrus hubs to reduce transportation costs, CO_2 emissions, and citrus loss and waste [25]. Alzubi et al. studied the dynamics of citrus production in the Jordan Valley, emphasizing loss and waste reduction at the farm stage and identifying best practices to enhance the sustainable performance of citrus supply chains [26].

Circularity was the main concern of Cheraghalipour et al., who studied a citrus fruit closed-loop supply chain, where waste (spoiled fruits) is transferred to vermicomposting facilities [27]. Goodarzian et al. discussed sustainability pillars, proposing a bi-objective mathematical model that minimizes total cost and CO_2 emissions of the supply chain network [28]. The model determines optimal production, allocation, and inventory decisions, while considering water resource limitations, land recultivation after harvesting, and time windows for product delivery to markets. Roghanian and Cheraghalipour extended Cheraghalipour et al.'s study by adding an objective function to reduce the CO_2 emissions produced by different types of vehicles [29]. Liao et al. developed a location–allocation model for a closed-loop supply chain for citrus fruit crates to reduce costs and emissions, including a reverse supply chain for plastic crates transported to recycling facilities, supporting the circularity concept [30]. Goodarzian et al. proposed a sustainable circular citrus closed-loop supply chain configuration that integrates circular economy and sustainability concepts, seeking to find the optimal configuration that minimizes the total cost and environmental impact and establishes centers in areas with smaller populations [31].

The economic pillar was the sole objective in Sahebjamnia et al.'s research, which aimed to maximize network profit while minimizing total costs through a mathematical model optimizing the allocation and transportation decisions along the citrus supply

chain [32]. Similarly, Goodarzian and Fakhrzad introduced a multi-objective mathematical model for designing a citrus supply chain network that minimizes total cost and maximizes profit, considering waste costs in their model [33].

Table 1. Research topics per reviewed paper.

No.	Reference	Facility Location/Allocation	Cold Chain	Ordering Process	Pre-HarvestingBest Practices	Traceability	Quality	Pricing	Resources	Time Window	CO2 Emissions	Economic	Social	Waste & Residuals	Crates	Circularity
1	[20]		x			x										
2	[23]			x		x	x	x				x				
3	[27]	x										x		x		x
4	[24]			x		x	x	x				x				
5	[29]	x									x	x		x		x
6	[21]		x													
7	[30]	x									x	x			x	x
8	[32]	x										x				
9	[33]	x										x		x		
10	[28]	x							x	x	x	x				
11	[25]	x									x	x		x		
12	[26]				x							x	x	x		
13	[31]	x									x	x	x	x		x
14	[22]		x			x										

5.2. Research Methodology

This section provides a thorough examination of the research methodologies applied in the reviewed papers. Two main methodologies were identified: case study and modeling. As shown in Table 2, most research within the citrus supply chain field applied a modeling approach. Research efforts in Africa focused on case studies, while Middle Eastern and European Union research centered on modeling approaches.

Table 2. Applied research methodology per reviewed paper.

No.	Reference	Case Study	Modelling	Modelling Approach
1	[20]	x		
2	[23]		x	MILP
3	[27]		x	Multi-objective (MILP)
4	[24]		x	MILP
5	[29]		x	Multi-objective (MILP)
6	[21]	x		
7	[30]		x	MILP
8	[32]		x	Multi-objective (INLP)
9	[33]		x	MINLP
10	[28]		x	Multi-objective (MINLP)
11	[25]		x	ILP
12	[26]		x	System Dynamics
13	[31]		x	Multi-objective (MILP)
14	[22]	x		

Further analysis reveals that almost half of the modeling-based papers incorporated multiple objectives and utilized mixed-integer linear programming (MILP) models. This approach suggests a focus on developing optimization-driven solutions to address the complexities inherent in citrus supply chain management.

The case study approach was employed in three articles. Defraeye et al. compared the performance of different ambient loading practices applied to exported citrus fruits overseas, monitoring parameters such as cooling rate, shelf life, and quality throughout the cold chain [20]. Goedhals-Gerber and Khumalo studied the different stages of South Africa's export cold chain of navel oranges to determine where temperature changes may occur [21]. Khumalo et al. presented an overview of temperature loggers used in South Africa's citrus cold chain [22]. Through interviews, they identified the benefits and drawbacks of tracking citrus fruit shipments at different stages using both traditional and cellular temperature loggers, finding that cellular loggers offer greater product visibility by monitoring the citrus fruit temperature in real time.

The modeling approach was utilized in most studies, employing various types of models. Three articles used the MILP methodology to model the citrus supply chain. For example, Liao et al. focused on optimizing the flow and location of facilities in a closed-loop supply chain of packaging crates for citrus fruits in Iran [30]. The model minimizes costs and emissions and was solved using simulated annealing (SA), genetic algorithm (GA), Keshtel algorithm (KA), and hybrid algorithms. Grillo et al. supported the complex order-promising process in the fruit supply chain, considering product subtypes and pricing based on freshness [23]. The model includes two conflicting objectives (maximizing profits and mean freshness) and was applied to orange and tangerine supply chains in Spain. Grillo et al. further introduced possibilistic variables to address product non-homogeneity and a state function to link product price with its lifetime in the order-promising process [24]. Goodarzian and Fakhrzad proposed a mixed-integer non-linear programming (MINLP) model for a four-echelon citrus supply chain, minimizing total cost and maximizing profit while considering various constraints [33]. They solved their model using three metaheuristic algorithms: ant colony optimization (ACO), SA, and a multi-objective ACO. Alzubi and Noche studied the introduction of collection points and citrus hubs in the citrus supply chain structure in Jordan to reduce citrus loss and waste [25]. They developed an integer linear programming (ILP) model to determine the number, location, and capacities of the collection points, minimizing the distance between farms and collection points. They evaluated suggested locations for a citrus hub using the center of gravity method to determine a sustainable location that minimizes transportation costs and CO_2 emissions. Alzubi et al. used a system dynamics (SD) methodology to identify best practices that improve the financial, social, and environmental performance of citrus farmers in Jordan [26].

A multi-objective mathematical model was considered in several research works. Cheraghalipour et al. proposed a bi-objective MILP model to increase customer demand responsiveness and reduce supply chain costs within a citrus fruit closed-loop supply chain [27]. The model was applied to a case study in Iran and was solved using multi-objective KA, multi-objective SA, non-dominated sorting genetic algorithm (NSGA-II), and non-dominated ranking genetic algorithm (NRGA). Similarly, in an extension of this work, Roghanian and Cheraghalipour incorporated various types of vehicles to transport products and introduced an environmental objective to minimize the CO_2 emissions generated from vehicles [29]. They proposed five meta-heuristic algorithms to solve the model. Goodarzian et al. optimized location, production, transportation, and inventory decisions to configure a sustainable closed-loop citrus supply chain [31]. The developed MILP model has three objectives related to economic, environmental, and social aspects. The proposed model was solved using the ε-constraint method and two metaheuristic approaches and applied to a case study in Iran. Sahebjamnia et al. developed a multi-objective integer non-linear programming (INLP) model to maximize network profits and minimize total costs, solving the model using three meta-heuristic algorithms (MOPSO, MOICA, and NSGA-II) [32]. Goodarzian et al. formulated a bi-objective MINLP model for the production–allocation–inventory problem in a three-echelon supply chain [28]. The model aimed to minimize the total cost and CO_2 emissions simultaneously, while considering the required water for cultivation and time windows for delivering to citrus markets. They utilized four

metaheuristic algorithms and a hybrid algorithm, namely MOACO, MOSA, NSGA-II, Fast PGA, and HACO-SA, to solve their model.

5.3. Supply Chain Echelons

The current review examines the focal echelons comprising the citrus supply chains investigated across the literature. Table 3 illustrates the supply chain echelons within the reviewed papers. The most addressed echelons are farms and distributors, due to their importance in producing and distributing citrus fruits in the supply chain. Conversely, the least mentioned echelons are related to incorporating circularity in the supply chain, such as collection centers, manufacturers/recyclers of fruit crates, and composting centers/markets. Interestingly, these circularity-oriented echelons were confined to the Middle Eastern studies included in the review.

Table 3. Supply chain echelons per reviewed paper.

No.	Reference	Farm	Packhouse	Distributor	Transport	Retailer/Market	Consumer	Manufacturer	Collection Center	Composting/Recycling Center	Compost Market
1	[20]				x						
2	[23]		x				x				
3	[27]	x		x		x				x	x
4	[24]		x				x				
5	[29]	x		x	x	x				x	x
6	[21]	x	x		x						
7	[30]	x		x		x	x	x	x		
8	[32]	x		x	x		x				
9	[33]	x	x	x	x	x					
10	[28]	x		x		x					
11	[25]	x	x	x					x		
12	[26]	x				x					
13	[31]	x		x		x				x	x
14	[22]				x						

Despite the importance of studying the complete chain, none of the reviewed papers incorporated all the echelons, which is a weak point in these studies. A few studies, such as those by Liao et al., Goodarzian and Fakhrzad, and Roghanian and Cheraghalipour, covered most of the supply chain, ensuring that all stakeholders are integrated [29,30,33]. This strengthens the work's outcome, as it mirrors the effect of any study on all stakeholders. In contrast, the majority of the studies concentrated on specific echelons, empowering the results from the perspective of these stakeholders only, without reflecting on their influence across the rest of the chain.

According to Table 3, it is apparent that the Middle Eastern papers boast the most comprehensive supply chain coverage, particularly the farms and distributor's echelons. The European Union papers exhibit gaps in the farm, distributor, transport, and retailer echelons. Finally, the African papers concentrated more on the transportation echelon due to the nature of the problems addressed.

6. Citrus Supply Chain Structure

The citrus supply chain diagram is a valuable tool, offering a simplified yet comprehensive visualization of the complex processes within the supply chain, spanning from the initial cultivation stages to the final point of consumption. This diagram not only aids in understanding the entire supply chain but also plays a crucial role in identifying potential bottlenecks and challenges, thereby presenting opportunities for enhancement and optimization. Real-world supply chains can be significantly more complicated, often encompassing a network of numerous suppliers, manufacturers, distributors, and retailers, each adding layers of complexity to the overall processes.

The citrus supply chain diagram was created by analyzing the supply chain models previously discussed and investigating specific case studies of real citrus supply chains. This diagram was then validated through several workshops and interviews involving various stakeholders in the field of citrus across the European Union, Africa, and the Middle East. Figure 15 provides a comprehensive overview of the citrus supply chain. Given that citrus fruit can be transformed into numerous products, each with its own unique path, the supply chain can become quite complex. To simplify this complexity, a streamlined representation is presented in the figure. The presented supply chain encompasses three main flows: citrus fruits processed solely at the packhouse; citrus products such as juice and jams; and residuals from the processing facilities (processor A and processor B). The supply chain can be categorized into two primary sections: domestic and international.

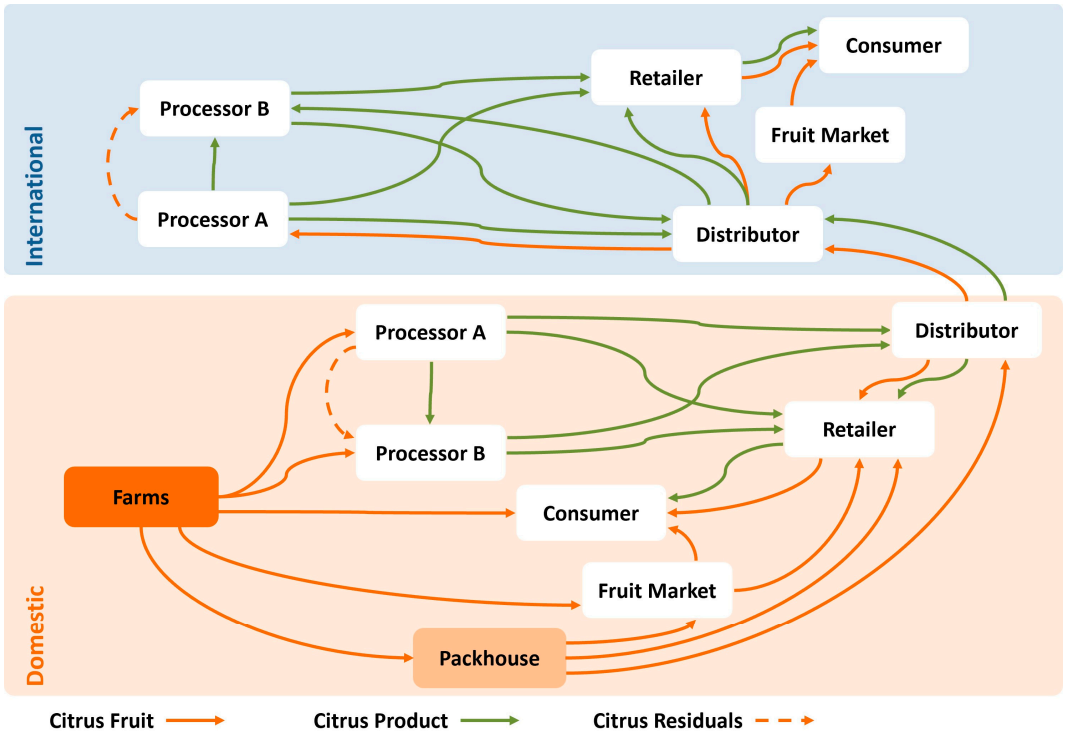

Figure 15. Citrus supply chain diagram.

In the domestic section, the supply chain begins at farms, where citrus fruits are grown and harvested. The harvested fruits are then sent to a packhouse, processor A, processor B, and/or fruit market; in some cases, fruits can be sold directly to consumers. The packhouse is where fruits undergo various processes, such as cleaning, sorting, and packaging, and are then prepared to be sent to distributors, fruit markets, and/or retailers. At processor A, citrus fruits are transformed into primary citrus products. These could be basic products such as fresh juice ready for consumption or juice concentrates. Some of these primary products are then sent to processor B, which produces secondary citrus products. These could be products such as marmalades, jams, canned fruits, or other processed food items.

Processor B may use the processing fruit residuals from processor A or lower-grade fruits from farms directly. The different roles between processor A and processor B allow for a wider variety of products to be produced from the harvested citrus fruits. The primary and secondary citrus products are then sent to distributors and retailers for sale. The fruit markets and distributors could be wholesale markets where retailers purchase stock, while the retailers could be supermarkets or stores where consumers can purchase fruits and/or products.

Some of the domestically produced citrus fruits and products are exported to international markets. The international section is similar to the domestic section explained earlier, involving distributors, processors A and B, fruit markets, and retailers in the supply chain. The primary distinction lies in the operation of these entities within international markets, where they engage in the import and export of citrus fruits and products. The international supply chain commences with the distributors and may encompass additional processing stages. Furthermore, it could potentially employ distinct distribution channels for the primary and secondary products. It is important to note that this illustration is a simplified representation of the citrus supply chain. Real-world supply chains can be much more complex with multiple intermediaries, various transportation methods, and numerous regulatory checkpoints. Additionally, factors such as seasonality, market demand, trade policies, and logistical challenges can greatly influence the flow presented in the citrus supply chain diagram.

The citrus supply chain is a complex system with numerous inputs and outputs at each stage. Understanding the material flows within the supply chain from a sustainability perspective is key to identifying opportunities for waste reduction and efficiency improvements. By effectively managing these inputs and outputs, their environmental impact can be minimized, thereby contributing to the sustainability of the citrus industry. This analysis serves as a valuable tool for stakeholders in the citrus supply chain to make informed decisions towards more sustainable practices.

The material flow from a sustainability perspective is illustrated in the following figures at each stage of the supply chain, considering the potential inputs and outputs at each stage. The initial stage in the citrus supply chain is the citrus production process at farms. Securing a successful harvest and maintaining the quality of the citrus relies on various inputs at the farm level, as shown in Figure 16.

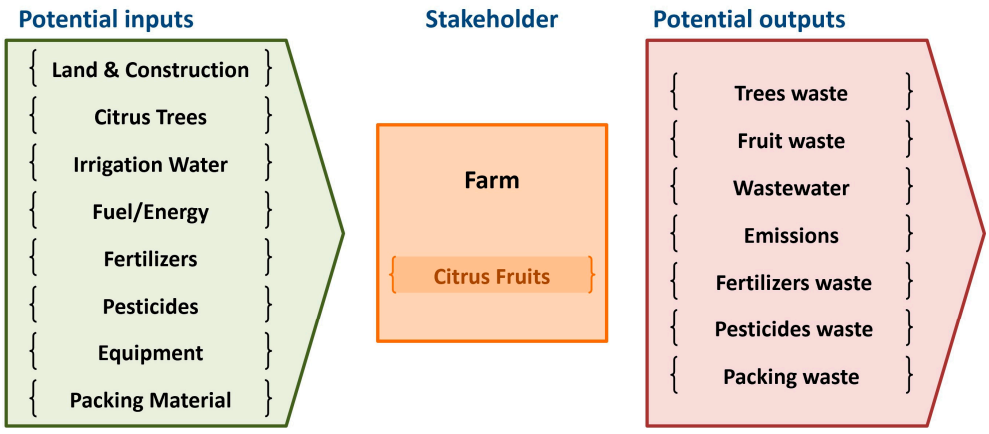

Figure 16. Potential material flow at citrus farms.

The potential inputs at the farm include land and construction, citrus trees, irrigation water, fuel/energy, fertilizers, pesticides, equipment, and packing material. The potential outputs involve various types of waste such as tree waste, fruit waste, wastewater, emissions, fertilizers waste, pesticides waste, and packing waste, along with the primary output at the farm, which is the citrus fruits (shown under the name of stakeholder "Farm" in the

figure). Citrus fruits, being the foundation of the citrus supply chain, serve as the main input to all the subsequent stages.

In the processing stage, including the packhouse, processor A, and processor B, the raw materials are converted into finished products. Inputs at this stage include land and construction, water, fuel/energy, equipment, and packing material, as shown in Figure 17. Given the variety of processors mentioned earlier, the raw materials can vary depending on the role of the processor, with citrus fruits, citrus products, and/or citrus by-products being the key input(s) for the processor (shown in orange within the inputs in the figure). The expected outputs, other than the primary product itself (shown under the name of stakeholder "Processor" in the figure), are fruit waste, process waste, wastewater, emissions, packing waste, residuals, citrus product waste, and by-product waste.

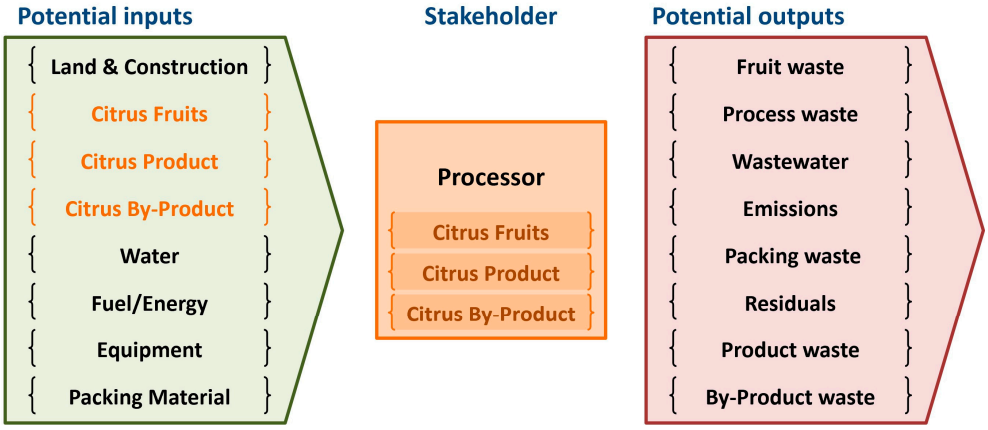

Figure 17. Potential material flow at the processing stage.

Figure 18 illustrates the distributor/retailer stage. Inputs are similar to those of a processor but tailored to distribution/retail needs, while the outputs focus on product and packing waste along with emissions. At the distributor stage, citrus fruits, citrus products, and by-products arrive at distribution centers or warehouses before further distribution to various types of processors or retailers. Outputs at this stage include fruit waste, citrus product waste, by-product waste, emissions, and packing waste, both at the facility and during transportation. Alternatively, citrus fruits and citrus products may bypass distribution centers and head directly to retailers, leading to outputs such as fruit waste, citrus product waste, emissions, and packing waste. Ultimately, consumers are integral contributors to the supply chain by generating fruit waste, citrus product waste, wastewater, emissions, and packing waste, as they interact with the citrus products.

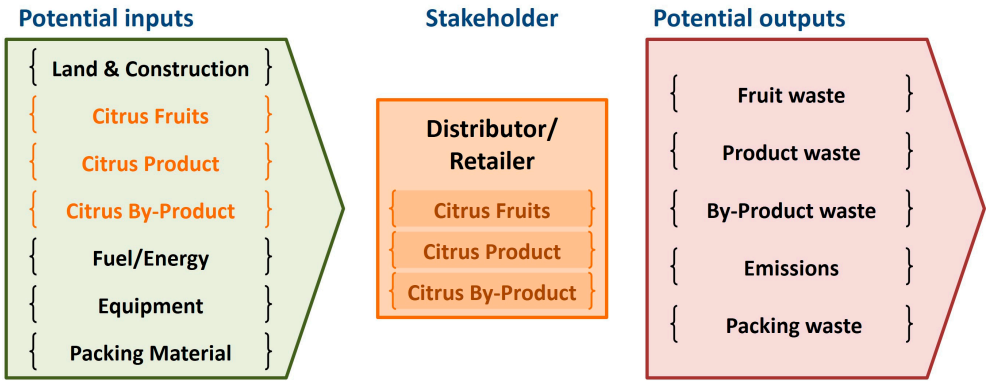

Figure 18. Potential material flow at the distribution/retail stage.

7. Conclusions and Future Work

7.1. Conclusions

Citrus fruits have significant economic and social impacts, as they are among the most produced and traded agricultural products worldwide. While previous research has addressed various topics within the overall agri-food supply chain (AFSC), there is a lack of product-based systematic reviews that offer an in-depth examination of specific AFSCs. Additionally, literature on the citrus supply chain in the European Union, Middle East, and Africa is scarce, despite the importance of citrus fruits in these regions. Therefore, this research reviews the citrus supply chain literature pertaining to these three regions.

A bibliometric analysis was conducted on the reviewed papers, followed by a content analysis to identify the addressed research topics, methodologies, and supply chain echelons, thereby revealing research gaps. Additionally, a citrus supply chain diagram was provided, based on real case studies and stakeholder interviews, outlining potential inputs and outputs at each echelon from material flow and sustainability perspectives. These outputs serve as a foundation for academics to create optimization models, conduct life cycle analyses, or integrate them into specific case studies. Practitioners can use these outputs to identify improvement areas and strategies to enhance the sustainability and profitability of the supply chain.

More research has been conducted on the citrus supply chain in the Middle East compared to Africa and the European Union. However, there is a lack of research on the citrus supply chain in Egypt and Turkey, despite being top citrus producers in the Middle East. Four main research themes emerged from the reviewed literature on the citrus supply chain in the European Union, Middle East, and Africa: (1) facility location and allocation, (2) cold chain management, (3) order-promising process, and (4) pre-harvest best practices. The reviewed literature reveals regional differences in the focus on various aspects of the citrus supply chain, with a predominant emphasis on facility location and allocation, and limited coverage of sustainability's social dimension and emerging topics such as resource considerations and time factors.

Regarding the methodologies applied, there is a predominance of modeling-based research methodologies in the citrus supply chain literature, with notable regional distinctions. The African context relied more on case study methods, while Middle Eastern and European Union studies favored modeling techniques, particularly MILP models with multiple objectives, to tackle the complexities of the citrus supply chain.

Research on the citrus supply chain has mostly concentrated on the farm and distributor stages, with little attention paid to the circular and sustainability-oriented supply chain stages. The differences in the scope and emphasis of the supply chain echelons examined across the three regions underscore the contextual variations in research priorities and the need for a holistic, cross-regional understanding of citrus supply chain management.

Despite the contributions of this study to the citrus supply chain research field, there are some limitations. Firstly, the literature review was conducted using three databases, which may have led to the omission of relevant studies indexed elsewhere. Secondly, the search was confined to English articles published from 2016 to 2023, excluding studies in other languages or those published outside this period. Thirdly, this study reviewed papers related to specific regions. Future research could address these limitations to provide a more extensive understanding of the citrus supply chain.

7.2. Future Work

The reviewed literature highlights several important research directions. Firstly, given the critical role of citrus production and trade in Africa and the European Union, more comprehensive studies on citrus supply chain management in these regions are needed. Secondly, while facility location and allocation were the most addressed research topics, there is still room for more studies on cold chain management, ordering processes, and pre-harvest best practices. As European Union and Middle Eastern studies focused on ordering processes and cold chain management, respectively, there is a need for studies

addressing facility location and allocation, considering circularity and sustainability aspects. Given the crucial role of some Middle Eastern countries in the global citrus market, more studies on pre-harvest best practices are needed to enhance the sustainability of citrus supply chains in this region. Future research in all regions should seek to fill literature gaps by examining various aspects of the citrus supply chain, such as time windows, resource utilization, quality considerations, fruit crates, and social sustainability.

Thirdly, more application of modeling techniques is necessary for research on the African citrus supply chain. Future research frameworks may utilize a methodology that combines case studies and modeling to take advantage of the benefits of both methods, leading to a more comprehensive understanding of the issues encountered by the citrus supply chain across different areas. Finally, further research is needed to incorporate circularity echelons within citrus supply chains. Different echelons, such as retailers, distributors, and transport, were not tackled in European Union studies and could be addressed in future research. Additionally, the processor echelon was not addressed across all regions, despite its importance in adding value to citrus fruits.

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