logistics

Review

Optimization Models for Harvest and Production Planning in Agri-Food Supply Chain: A Systematic Review

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Abstract: This paper provides a comprehensive review of the research done on optimization models that focus on harvest and production planning for food crops. Optimization models have been used extensively in providing insights to decision-makers on issues related to harvest and production planning in agri-food supply chains. First, we conduct an extensive literature review on previous survey articles to distinguish our research from others. Based on the previous reviews, a new classification scheme is developed to classify articles systematically. Harvest and production planning problems in agri-food supply chains are analyzed through three sections: problem scope, model characteristics, and modeling approach. Neglected problem topics and several promising research directions are presented to stimulate research interest on agri-food supply chains specifically planning of harvest and production.

Keywords: agri-food supply chain; harvest planning; production planning; literature review

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1. Introduction

Agri-food supply chains (AFSCs) comprise several activities to provide agricultural products from farms to tables to satisfy customers' demands [1]. A supply chain of agri-food products mainly includes cultivation, harvesting, processing, distribution, and storage activities [2]. These activities can be performed with the participation of farmers, processors, cooperatives, regulators, transporters, research institutes, traders, retailers, and customers [3]. Figure 1 presents an outline for the main AFSC actors.

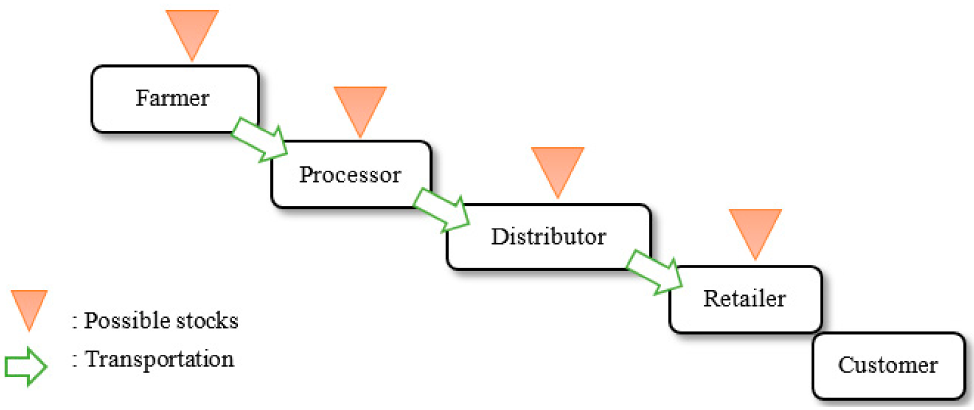

Figure 1. Generic AFSCs (based on [2,3]).

Some studies categorize AFSCs from different perspectives. Ref. [4] classify agricultural products into two main categories: crops and livestock. Crops are the products obtained directly from plants, while livestock includes animal-related products such as meat, cattle, seafood, dairy, and wool. Ref. [2] differentiate agri-food products, fresh products (preserve original characteristics e.g., packaged food), and processed products (value-added products e.g., canned food, juice). On the other hand, [1] state two main types of agri-foods: perishable (e.g., vegetables and fruits) and non-perishable (e.g., grain, nuts).

AFSCs are more complex and difficult to manage than other supply chains because of some specific and inherent characteristics. These characteristics are perishability in supply chain stages, limited shelf life, seasonality of agri-food production, variability of weather conditions, fluctuations in yield and demand, required specifications regarding the storage and transportation conditions, food quality and safety, regulations to follow in all stages, price variability [1–3].

AFSCs are accountable for providing agricultural products [5] and therefore influence the daily life of consumer society. Adapting to the global agri-food industry, responding to consumer demands, industrialized agricultural production, product safety requirements are examples of AFSCs' challenges [3]. Correspondingly, AFSC management has gained more interest in recent years.

Today's one of the biggest challenges for the supply chain actors is that following up the new trends, regulations, and policies. Actors try to meet the local and global demand for their products while making an effort to improve their operations. AFSCs along with effective and efficient planning could minimize costs, reduce carbon footprint, minimize waste, provide resilient and robust supply chains, and so on. The objective of this paper is to give an understanding of current addressed problems in AFSCs and how considered problems are changing according to the requirements.

The present review mainly focuses on harvest and production planning, since they represent the most important portion of the planning activities performed by AFSCs. Optimization models are powerful tools to tackle planning problems. Over the past ten years, a considerable amount of research has been devoted to the development of optimization models to support decision-makers in AFSC management.

Harvest and production planning activities are crucial for obtaining desired crops and products in the context of AFSC management. Despite the increasing research in the last decade, harvest and production planning studies still need to be developed for the encountered challenges. Hence, we seek to demonstrate harvest and production planning problems in the AFSCs to convey trends and gaps in the literature through the following research question:

RQ1. How are the harvest and production planning problems in AFSCs evolving with inherent challenges and complexities over the years?

This review aims to establish a framework to analyze the existing literature on harvest and production planning problems in AFSCs. Thus, a framework based on problem scope, model characteristics, and mathematical modeling is developed, and then AFSC concepts and differences are investigated. Research gaps and trends are discussed for future research opportunities.

The rest of the review is organized as follows. In Section 2, an overview of previous review studies is stated. In Section 3, the proposed review methodology for this review is addressed. In Section 4, a review of the selected articles is presented. In Section 5, the results from the systematic literature review, and future research directions are discussed. Finally, in Section 6, a conclusion is presented.

2. Previous Reviews

In recent years, several review studies have been conducted focusing on agricultural supply chains. Related previous review studies are investigated in this section, and Table 1 briefly displays their scope. Articles are ordered chronologically.

Table 1. Previous review studies.

Reference	Objective of the Research	Prominent Future Research Opportunities
[6]	Point out operations research models on agricultural planning at the farm level	Farm planning models that convenient to use by individual farmers, development of research tools
[7]	Highlight the operation management problems of crop production	Efficient management of transportation, distribution, and inventory management
[1]	Evaluation of production and distribution planning models	Operational models which integrate production and distribution decisions, models that include uncertain information
[8]	Provide possible improvements for the decision-making process and future research areas for academics	Operational research for individual growers, food security, interdisciplinary research, risk management
[9]	Present literature review on operational issues that cause post-harvest losses of fresh produce	Demand forecasting, harvest scheduling, integration of production and inventory for fresh produce
[3]	Provide a framework for natural decision-making process on designing AFSCs	Integrated systematic approach on agri-food, real-time optimization tools for dynamic and stochastic nature
[2]	Investigate the modeling approaches for operational models on harvesting and processing planning	Integration of harvesting and processing models, including sustainability, incorporating harvesting time window, yield perishability, inventory control
[10]	Review of the operational research models on fresh fruit supply chain	Holistic designs and management, organic fruit production, climate adaptation, food security, integration of sustainability
[11]	Deliver a wider perspective of quality measures in fresh AFSCs	Research in developing countries, realistic research models, information management, and collaboration with suppliers for quality
[4]	Review quantitative risk management models in agribusiness supply chains	Modeling perishability, considering supply and demand risks, multi-period modeling, resilient strategies
[5]	Propose a conceptual framework for AFSC designs and present a review of mathematical models	Integration of AFSC stages, including multiple products and product characteristics, the inclusion of multiple objectives, incorporating uncertain elements
[12]	Determine the literature of AFSC management and assess the structures of the models	Research in developing countries, integration of sustainability, resilience in AFSCs
[13]	Find ways of applying the multidisciplinary concept to the AFSCs	Empirical validation of the developed framework, applying the framework to the developing world countries
[14]	Address a research agenda for the application of information technology opportunities in the fresh produce supply chain	Real-time data inclusion, including new sensor and information technologies
[15]	Find answers to how to achieve sustainability in a data-driven AFSC	Improving supply chain visibility, using blockchain technology, internet of things applications, new data collection ways
[16]	Review of sustainability-driven agricultural supply chain management models	Reverse logistics and closed-loop supply chains for agricultural systems, decentralized systems, analyzing logistic systems

Ref. [6] reviewed agricultural planning to address mathematical models on crop and livestock sectors. Later, [7] focused on modeling approaches in their review study to highlight the agribusiness problems on crop planning, harvest planning, and risk management. Ref. [1] presented a review of production and distribution planning models for agricultural products. They classified the articles into two main categories, perishable and non-perishable agricultural products. Also, articles were evaluated according to their planning scope, decision variable, and modeling approach. On the other hand, [8] considered only the specialty crops industry and reviewed operational research models. This review included fruits, grapes and wine, floriculture, tree nuts, berries, and dried fruits.

In their extensive review, [9] presented the existing literature of fresh produce covering fruits, flowers, and vegetables. The articles were analyzed by focusing on operational problems that cause post-harvest wastes. They classified the articles in terms of demand forecasting, production planning, inventory management, and transportation. Ref. [3] conducted a review on the design and management of AFSCs and classified papers in terms of strategic, tactical, and operational decision levels. By focusing on harvesting and processing activities in the agricultural supply chain, [2] reviewed the literature and indicated the need for integrated planning models. Operational research models in the fresh fruit supply chain were investigated by [10]. They analyzed the literature in terms of decision level, modeling approach, and purpose of the study, application type, novelty, and research segmentation by journal. Within the context of the AFSC, [11] conducted a comprehensive literature review focusing on supply chain quality. Three crucial quality elements for AFSCs were identified as information, sustainability, and logistics management. Ref. [5] suggested a conceptual framework for the design of AFSCs addressing chain characteristics, uncertainty modeling, decision characteristics, and modeling approaches. Following that, a comprehensive review was conducted for mathematical programming models. Ref. [12] investigated the existing literature from 1985 to 2017 in AFSC management via bibliometric and content analysis. The bibliometric analysis contains author influence, journal quality, affiliation statistics, and citation analysis. As a result of the content analysis of 188 articles, six different research areas were generated.

Ref. [4] classified the risk management papers in agribusiness according to product types, risk types, risk management strategies, and modeling approaches. They summarized risk under the two categories of supply-side and demand-side risks. While food safety, crop yield, harvest yield, crop price, spot price, climatic variations, harvest maturity, uncertain length of the harvest season, lead time uncertainty, raw material quality, harvest time are considered as supply-side risks; demand size, crop, and product price, yield dependent price uncertainty are considered as demand-side risks in the literature. Ref. [13] provided a systematic review of literature relevant to resilience in an AFSC. Afterward, according to the outcomes of the review, a framework that consists of specific resilience elements and strategies for the AFSCs were stated. Ref. [14] reviewed information technologies that support decision-making in the fresh produce supply chain.

A recent review study was presented by [15] to investigate the literature on the sustainable agricultural supply chain in a data-driven environment. They also provided a framework focused on supply chain visibility, integration of resources, sustainable performances, and data analytics capability to aid decision-makers. Ref. [16] conducted a comprehensive review consisting of 247 quantitative articles on sustainable agricultural supply chains. Articles were reviewed regarding four research fields: agricultural planning, supply chain management, sustainability development, and modeling methodology.

All of the previously published review studies have different emphasis on AFSCs such as risk management [4], resilience [13] or sustainability [16], data-driven AFSC, and information technology [14,15]. Note that all of these review papers are in the area of AFSC, but only some of them explore the studies that have been made in both harvest and production planning, though their scope is different. Of the papers reviewed in this section, the paper presented by [2] is the only one that addresses both harvesting and processing activities. They firstly reviewed harvesting and processing related papers individually and then focused on integrated harvesting and processing models. They mainly investigate whether harvesting and processing activities were studied separately or simultaneously. Additionally, models for both food and non-food crops are selected for their review. Their literature search has been carried out through ISI Web of Science in April 2014. Different from the review paper by [2], this paper examines optimization models for harvest and production planning-related problems in the AFSC management, has a more comprehensive classification framework, and only considers food-crop related problems.

As displayed in Table 1, to the best of our knowledge, there is no recent review paper on optimization models which focus on both harvest and production planning. Unlike previous review papers, the present paper aims to fill a gap in the literature by providing a systematic literature review of optimization models on harvest and production planning for food crops in AFSCs. A novel classification framework is developed to study harvest and production-related problems in the agri-food industry. We investigate the trends and gaps in an attempt to gain a better understanding of the existing literature. Additionally, we highlight some prominent research opportunities for future considerations.

Previous review studies provide an understanding of AFSC systems and hence more detailed questions are asked to elaborate *RQ1*. This review is seeking answers to the following sub-research questions:

RQ1.1. Which type of decision variables and objective functions have been used to design harvest and production planning in AFSCs?

RQ1.2. What type of crops and characteristics have been investigated in the harvest and production planning studies?

RQ1.3. Which solution methodologies have been used to address the problems?

3. Review Methodology

In light of the knowledge gained from previous reviews, a novel classification scheme is developed for this systematic literature review. Then, research methodology is stated to understand the scope and limitations of this study.

3.1. Classification Scheme

The main purpose of this classification is to form a framework for our research. A new classification scheme (Figure 2) is developed based on the studies of [2,5,10].

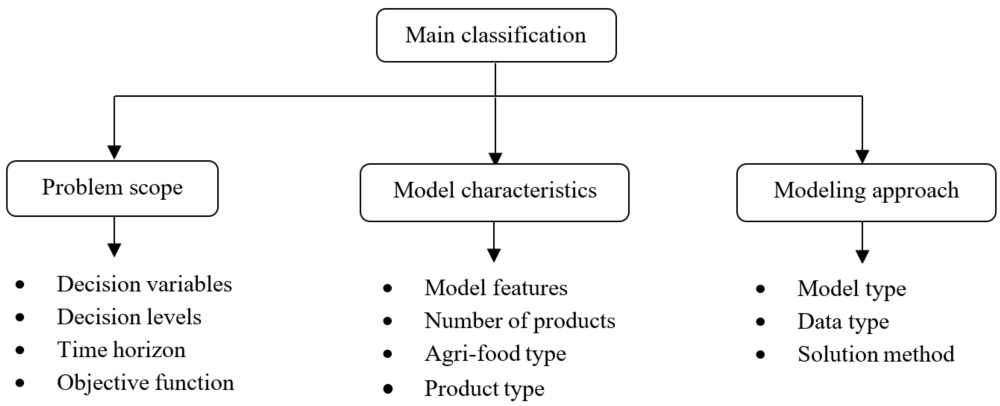

Figure 2. Classification scheme.

First of all, articles are classified based on their problem scope. AFSCs may include different supply chain activities, thus related five types of decision variables are determined. Decision variables are related to cultivation planning (e.g., decisions on selecting crops and land), harvest planning (e.g., decisions on scheduling, routing), production planning (e.g., decisions on processing, packaging), distribution planning (e.g., decisions on transporting and shipping), and inventory planning (e.g., decisions on managing inventory). Three decision levels are considered: strategic as long-term decisions, tactical as medium-term decisions, and operational as short-term decisions. Technology selection, supply chain designs, crop rotation planning, capacity planning can be considered strategic decisions. Tactical decisions cover crop selection, planting, and harvest planning. Production scheduling, inventory, equipment scheduling can be considered as operational decisions [1]. Additionally, articles are investigated to determine planning horizons whether single-period or multiple-period. The objective functions of the optimization models are classified as profit maximization, cost minimization, and other objectives. Secondly, model characteristics are indicated. AFSC problems can take into account several features according to the problems' nature. Considered model features are time window, perishability, resource limitations, uncertainty, product waste, and sustainability. Articles are also revised according to product characteristics. Single or multiple product considerations and fresh or processed agri-food production are investigated. In addition, product types that are considered in the AFSCs are displayed. Lastly, modeling approaches used are discussed. To display the validation and applicability of the models, articles that used either real case or hypothetical data are presented. Solution methodologies such as exact, heuristics, goal programming are pointed out.

3.2. Material Selection

This review is focused on published scientific articles which study AFSC problems. Papers were found from widely accessible online databases (Scopus, Elsevier, Web of Science, Google Scholar) with keywords such as: "agri-food supply chain", "agricultural supply chain", "harvest planning", "agri-food production", "processed agri-food", "vegetable supply chain", and "fruit supply chain". Because of the scope of this review, articles are restricted according to the following criteria:

- Optimization models are considered in the context of AFSCs. To exemplify, frameworks, exploratory research, simulation studies, and guidelines are excluded.
- Models which consist of at least one of the decision variables related to harvest planning and production planning are included.
- Articles addressing food-crops supply chains which provide food for human consumption are taken into account.

For example, products that are not directly related to food crops such as livestock and fish, biomass, wood, and floriculture are excluded.

According to the above criteria, articles were selected from the online databases stated above. In addition, some of the articles were obtained from the selected articles' and previous reviews' reference sections. Ultimately, after a content analysis, a total number of 74 papers published from January 2000 to October 2020 are reviewed, analyzed, and classified based on their problem scope, model characteristics, and modeling approach.

4. Review of Harvest and Production Planning in Agri-Food Supply Chains

In this section, a literature review on optimization models for harvest and production planning problems in AFSCs is presented according to the classification scheme.

Figure 3 indicates the number of papers published over the 20-year period regarding this review's criteria. Also, the articles' journals and countries are listed in Appendix A. The papers are ordered chronologically in all of the tables.

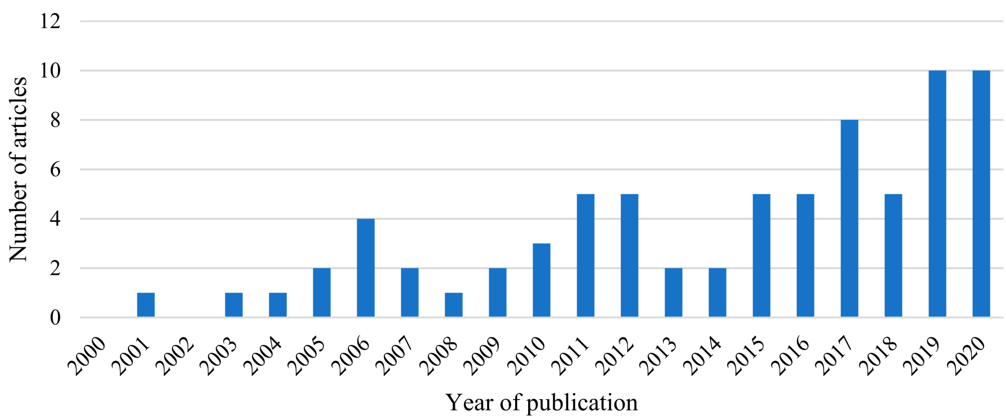

Figure 3. Publication date, distribution of reference papers.

4.1. Problem Scope

In this sub-section, we try to summarize the characteristics of the problems. Table 2 summarizes the reviewed literature. For each selected article studied, the table illustrates (1) decision variables related to AFSC, (2) decision levels, (3) time horizon, and (4) considered objective function(s).

4.1.1. Decision Variables

As stated earlier, our focus is on harvest and production planning models. Therefore, studies that contain at least one decision variable related to either harvest planning or production planning are selected. Problem characteristics and supply chain configurations are also addressed.

There are fourteen papers only focused on harvest planning. Ref. [17] clustered farms according to their sugar content patterns and then planned a harvesting schedule to maximize total sugar content in the sugarcanes. Ref. [18] optimized an orange harvesting schedule in orchards for juice extraction according to the maturation curve. In their pioneering paper, [19] presented an optimization model for wine grape harvesting operations to minimize harvesting operations costs and penalty costs for quality loss. The model comprises harvest scheduling, resource assignments, and routing decisions. Ref. [20] extended the model by [19] and developed a robust optimization model to address uncertain elements. Ref. [21] extended the study by [19] and developed a novel heuristic-based solution. In another study, [22] also extended the work of [19] and developed a multi-objective harvest scheduling problem aiming to maximize grape quality and minimize the cost of harvest operations.

Ref. [23] proposed a harvest scheduling model which seeks to minimize the costs. Costs are two-fold: costs from harvest resource utilization and penalty cost from the loss of apple quality. The decisions include the determination of harvest quantity, labor, and harvest means allocation. Ref. [24] developed a model that finds the optimal harvest schedule for a group of sugarcane farmers to maximize harvested sugarcane. Differently from other papers, [25] took into account harvest scheduling, maintenance scheduling, transportation means scheduling, and labor allocation simultaneously. Ref. [26] extended the study of [23] to include multiple orchards for harvesting operations.

Ref. [27] developed a decision support system for growers to sequence the harvesting operations throughout the entire harvest season in the sugarcane fields. On the other hand, [28] proposed a harvested resource scheduling problem to find the balance between the different harvest resource capacities and transportation capacity. The model presented by [29] tackled the two-echelon multi-trip vehicle routing problem for the decision-making in grain harvesting operations. The model minimizes the number of harvesters, total travel costs, and waiting time. Ref. [30] addressed the arc routing problem to optimize machinery paths for harvesting operations while minimizing total traversed length by vehicles.

Several articles consider both cultivation and harvest planning simultaneously. Ref. [31] aimed at determining a schedule of tasks that are needed for cultivation and harvest planning in the farm. The main contributions of the study are both presenting a novel 0–1 programming model and developing a new structure, so-called conditional disjunction. Ref. [32] proposed a framework to maximize sugar production according to the mill's capacity. Firstly, expected sugar yields are calculated by crop growth simulation, after optimum cultivar, planting and harvesting schedule is determined by a mathematical model. Ref. [33] consider the agricultural planning problem of a firm that contracts different farms under maturation time, harvest time, and yield uncertainty.

To address the need for recovering production wastes, [34] developed a closed-loop mushroom supply chain. The planning model consists of raw material production, mushroom cultivation, and selling mushrooms to consumers. Ref. [35] develop a stochastic programming model, which is based on the study of [34], to solve uncertainties in the industrial mushroom production supply chain.

Ref. [36] considered vegetable planting and harvesting decisions with the focus on immigrant and domestic labor force recruitment. Ref. [37] investigated the problem of assigning crops to each field and routing of multiple harvesters to minimize costs.

For harvest and transportation planning, [38] presented a framework for the sugar value chain and proposed two models. The transportation planning model decides the number and locations of the sidings while minimizing transportation costs. The harvest planning model assigns farms to harvest groups to minimize the total distance between them. Ref. [39] differentiated their study from the literature by including corporate social responsibility in a vegetable supply chain to enhance farmer's business skills. The model determines vegetable supply and allocation quantity and timing, training skills of farmers, and quality improvement percentage. The model maximizes farmer profit and retailer profit. Ref. [40] aimed to find a sugarcane harvest and transportation schedule to meet the model's goals which are to minimize the deviations in agricultural activity costs and optimal sugarcane content.

Inventory planning was integrated into a harvest planning model by [41] to design a short fresh product supply chain that includes the activities of harvesting at farms and meeting demands at retailers to maximize demand satisfaction. Ref. [42] addressed a problem where multiple farmers harvest and deliver agricultural fresh products to multiple markets.

Different from other studies, [43] investigated harvest scheduling problems by developing two different models for operational and tactical decision levels. Ref. [44] made a major contribution to the literature by proposing an olive harvest planning model for an olive oil mill. The model maximizes olive oil quantity from harvested olives. Moreover, different work teams with different resources, olives from external farmers, and severe weather conditions were incorporated into the model. Ref. [45] proposed an optimization approach for the coordination of supplying olives from farmers to produce olive oil in one common mill. Furthermore, [46] extended their previous study by presenting multi-objective programming for solving their mathematical model. The first objective aims to maximize olive oil producer's profit, the second objective aims to minimize olive farmers' costs.

Some papers developed more comprehensive models regarding harvesting decisions. Ref. [47] formulated two models for the optimization of supplying sugar cane to the sugar mill to produce raw sugar. The first model determines the cultivation planning, and the second model provides a harvesting schedule with the allocation of crew and equipment. The objectives of the models are maximizing milling requirement coverage and minimizing total cost for production, respectively. The study of [48] is distinguished from the literature by studying a vegetable crop rotation problem with the possibility of storing products to meet the demands. To evaluate spoiled products and hence to produce organic fertilizers, [49] addressed a closed-loop supply chain design model for citrus products. The model aims to minimize total cost and maximize responsiveness to satisfy customers. Ref. [50] extended the study of [49] by adding another objective function to consider sustainability in the supply chain. Ref. [51] developed a model to design a closed-loop sustainable supply chain for fruits. The model optimally determines forward and reverse flows, inventory, and facility locations. Ref. [52] studied the wheat supply chain which considers supplier selection, facility location for long-term and short-term storage, and inventory control decisions besides flow decisions.

Ref. [53] presented a two-stage stochastic production planning problem for a four-year period in the olive oil industry to maximize profit. In the first stage, the amount of olive trees to be leased is decided by the oil producer. In the second stage, depending on the olive yield and olive oil prices, the amount of olive to purchase from other farmers and olive oil quantity to be produced are decided. Ref. [54] extended the study of [53] by considering yield-dependent cost structure on pricing and olive oil production planning. Ref. [55] developed a model to determine the bottling schedule for wine products allocated to the production lines. The model minimizes the delay of all orders, final completion time for each order, and final processing time for each job. Ref. [56] implemented a stochastic model to determine an olive oil production schedule regarding the received olive's features.

Production and distribution planning problem was considered in several papers. Ref. [57] proposed a supply chain network design that targeted the Dutch market to minimize the total cost of producing pea-based protein. Ref. [58] studied an edible oil manufacturer's production and distribution network which consists of supplying oil from suppliers, storing crude oil and processed oil, processing oil at the refinery, and filling bottles to supply demands. Focusing on post-harvest losses, [59] explored a grain supply chain to include the decisions of harvest time, transportation, storage, grain purchase prices, and location selection. Due to the fact that sustainable AFSC design is challenging, [60] proposed a two-stage hybrid approach. In the first stage, potential supply chain partners are evaluated. In the second stage, according to partner evaluation, a generic AFSC design is presented. Ref. [61] presented a production and distribution network optimization model for production and shipment planning in an olive oil company.

Some models consider integrated inventory, production, and distribution planning decisions. Ref. [62] proposed a goal programming model by considering the production, distribution, and warehousing of frozen concentrated orange juice. Ref. [63] considered an international sugar supply chain that consists of the production, transportation, and storage of different sugar brands. Ref. [64] addressed the sugarcane supply chain problem with strategic and tactical decisions. Technology selection, transportation mode selection, capacity planning, and production planning were investigated. Ref. [65] proposed an optimization approach for a generic fresh food production and distribution plan and made an important contribution to the literature by determining temperature levels during transportation and storage. For rice processing, [66] investigated a rice mill complex design to optimize the production planning of rice products and by-products, technology selection for the complex, and distribution network. Supplying, storing, processing, and distributing unprocessed and processed grain products to domestic and external markets were investigated in the supply chain by [67]. Ref. [68] tackled the wheat-to-flour supply chain design problem to determine production, storage, and transportation quantities to meet domestic and external demands. To investigate heterogeneity and freshness in the fruit supply chain, [69] considered sourcing fruits from one field to process in multiple packing facilities and distributing products to multiple customers. They developed a model both maximizing profit and freshness of products. Ref. [70] considered a generic sustainable wine supply chain to select suppliers, establish wineries, bottling plants, and distribution centers, and determine production and transportation planning. Ref. [71] addressed a sustainable supply chain problem with a single supplier and multiple retailers to handle customer's demand for organic and conventional products. The model also investigates inventory planning and allows to substitute of conventional products with organic ones. Ref. [72] proposed a new integrated wheat supply chain network design considering sustainability and minimizing non-resiliency. The model components are domestic and external wheat suppliers, different wheat qualities, silos, flour factories, transportation modes, and demand zones.

The papers stated below considered cultivation planning and production planning and did not consider particularly harvesting decisions. The paper presented by [73] differs from the existing literature in terms of including renewable energy fields and plantings for carbon emissions from an interdisciplinary approach. In addition to this, agricultural lands, processing facilities, and warehouses are included. Ref. [74] focused their work on designing a green supply chain only at a strategic level. The distinguishing elements of this study are incorporating decisions for organic and conventional raw materials, investigating green consumer behavior, and selecting technology for juice production. Ref. [75] designed an integrated rice supply chain for planting, processing, and transportation planning. The highlights of this article are including fertilizer and pesticide suppliers, considering irrigation water consumption, and integrating different varieties of rice.

There are several comprehensive AFSC problems in the literature. A complex and detailed fruit supply chain tactical planning model which consists of many nodes and interactions was proposed by [76]. Essentially, the model determines the optimal quantities of fruit supplying, packaging, processing, storing, and transporting. Ref. [77] proposed an operational model which consists of harvesting, packing, storing, and distributing multiple fresh produce to customers. Ref. [78] developed an approach to tackle uncertainty and presented a two-stage stochastic model. In the first stage, planting decisions and labor requirements, in the second stage, harvesting and transportation decisions were determined. Ref. [79] extended the study of [77] by including post-harvest losses, water, and energy consumption in the supply chain. Ref. [80] presented a robust optimization approach for a model that integrates harvesting and processing of oranges and storing of orange juice. Ref. [81] proposed a tactical planning model which considers supplying fruits from owned and external farms, processing for juice production, packaging fresh produce, inventory management, and distributing to markets that have different quality requirements for products. The model aims to minimize fruit shortages and maximize total profit.

Ref. [82] addressed the production and logistics planning problem faced by a tomato processing industry. Then, [83] developed a robust optimization approach considering uncertainty in the tomato Brix, and crop yield parameters. Another example of AFSC design was proposed by [84]. They explored a distribution system among packing facilities, warehouses, cooling facilities, retailers, and processing plants. Ref. [85] proposed a framework to plan agricultural activities according to fresh fruits' and vegetables' optimal growth conditions while maximizing total profit. The goal of the framework is to find an optimal solution for planting, harvesting, and shipping schedules. Ref. [86] presented a model for rice supply chain design with decisions on providing rice from farmers, processing rice at mills, and storing products to meet demands. Ref. [87] developed a two-stage stochastic programming model for a local agri-fresh supply chain based on the study of [85]. In the first stage, the selection of agricultural technologies and planting decisions are made. In the second stage, under stochastic parameters, harvest scheduling is determined to meet the market demands. The objectives of the stages are minimizing costs and maximizing profit, respectively.

Regarding the consideration of all the decision variables of the AFSC, only three papers considered all of them. Ref. [88] presented integrated tactical planning for cultivation, harvest operations, packaging, storing, and transporting fresh products in the supply chain with the perspective of a grower. Ref. [89] proposed a multi-objective generic AFSC model which consists of planting, harvesting, processing, storing, and distributing at various locations. Ref. [90] consider all of the five decision variables and also facility location decisions for a sustainable wheat supply chain.

There are 32 papers dealing with harvesting-related planning, while 23 papers consider production planning problems. 19 papers presented studies that are related to integrated harvest and production planning.

4.1.2. Decision Levels

Out of 74 papers, 26 papers dealt with strategic decision level, 59 papers investigated the tactical decision level, only 21 papers related to the operational decision level. While 42 articles tackled only one-level decisions, 32 dealt with more than one decision level. For example, [31] took into account buying new equipment and harvest planning as strategic and operational decisions, respectively. Ref. [43] considered tactical and operational decisions for harvest planning. Technology and capacity selection and production planning were incorporated as strategic and tactical decisions by [66]. Decision levels are indicated in Table 2.

4.1.3. Time Horizon

Most of the models took into account multi-period planning horizons such as days (e.g., [19]) or weeks (e.g., [56]). Single period planning horizon mostly used to make strategic decisions (e.g., [33]). Multi-period planning horizon was considered by 60 papers, on the other hand, single-period planning horizon was taken into account by 14 papers.

4.1.4. Objective Functions

The objectives of the models are also indicated in Table 2. Most of the models consider economic objective function, either minimization of cost or maximization of profit as an objective. Only 9 articles did not include these objectives. Cost minimization is taken into account in 34 articles, while profit maximization is considered in 33 articles. Other objectives such as maximization of demand satisfaction (e.g., [42]) and olive oil maximization (e.g., [44]) have already been stated in Section 4.1.1. 21 of the papers presented multi-objective models to their comprehensive problems. In addition, sustainability-related objectives are discussed in sub-Section Sustainability.

Table 2. Classification according to problem scope.

Reference	Decision Variables					Decision Levels	Time Horizon	Objective Function		
	CP	HP	PR	DT	IN			CM	PM	OT
[62]			X	X	X	T	MP	X		X
[31]	X	X				S-O	MP	X		
[53]			X			S	SP		X	
[57]			X	X		S	SP	X		
[17]		X				T	MP			X
[18]		X				T	MP		X	
[38]		X		X		T	SP	X		X
[63]			X	X	X	T	MP	X		
[41]		X			X	T	MP			X
[47]	X	X		X	X	T-O	MP	X		X
[76]		X	X	X	X	T	MP		X	
[19]		X				T-O	MP	X		
[42]		X			X	T	MP			X
[32]	X	X				T	MP			X
[21]		X				T-O	MP	X		
[20]		X				T-O	MP		X	
[45]		X	X		X	T-O	MP		X	
[88]	X	X	X	X	X	T	MP		X	
[77]		X	X	X	X	O	MP		X	
[54]			X			S	SP		X	
[64]			X	X	X	S-T	MP		X	
[65]			X	X	X	T	MP	X		
[78]	X	X	X	X		T	MP		X	
[58]			X	X		T	SP	X		
[27]		X				O	MP		X	
[39]		X		X		T	MP		X	
[33]	X	X				S	MP		X	
[43]	X	X	X			T-O	MP		X	
[66]			X	X	X	S-T	MP		X	
[48]	X	X		X	X	S-T	MP		X	
[80]		X	X		X	T-O	MP	X		
[40]		X		X		T	MP	X		X
[23]		X				T-O	MP	X		
[67]			X	X	X	T	MP		X	
[24]		X				T	MP			X
[36]	X	X				T	MP		X	
[73]	X		X	X		S	SP	X		
[59]			X	X		S-T	SP		X	
[81]		X	X	X	X	T	MP		X	X
[82]		X	X	X	X	T	MP	X		
[83]		X	X	X	X	T	MP	X		

Table 2. *Cont.*

Reference	Decision Variables					Decision Levels	Time Horizon	Objective Function		
	CP	HP	PR	DT	IN			CM	PM	OT
[34]	X	X				T	MP		X	X
[55]			X			O	MP			X
[84]		X	X	X	X	S-T	MP		X	
[68]			X	X	X	S-T	MP	X		
[69]			X	X	X	T	MP		X	X
[44]		X	X			O	MP			X
[74]	X		X			S	SP		X	X
[70]			X	X	X	S-T	SP	X		X
[60]			X	X		S-T	MP	X		X
[49]		X		X	X	S-T	MP	X		X
[85]	X	X	X	X		S-T	MP		X	
[56]			X			T	MP		X	
[71]			X	X	X	T	MP	X		X
[35]	X	X				T	MP		X	X
[86]		X	X	X	X	S-T	MP	X		
[29]		X				O	SP			X
[46]		X	X		X	T-O	MP	X	X	
[89]	X	X	X	X	X	S-T	MP		X	X
[28]		X				O	MP	X		
[37]	X	X				T-O	SP	X		
[50]		X		X	X	S-T	MP	X		X
[79]		X	X	X	X	T-O	MP		X	
[61]			X	X		T	SP		X	
[25]		X				O	MP	X		X
[87]	X	X	X	X	X	S-T	MP	X	X	
[26]		X				T	MP	X		
[72]			X	X	X	S-T	MP	X		X
[51]		X		X	X	S-T	MP	X		X
[75]	X		X	X	X	S-T	SP		X	
[90]	X	X	X	X	X	S-T	MP	X		X
[30]		X				O	SP			X
[52]		X		X	X	S-T	MP	X		
[22]		X				T-O	MP	X		X

Note: CP: Cultivation planning, HP: Harvest planning, PR: Production planning, DT: Distribution planning, IC: Inventory planning, S: Strategic, T: Tactical, O: Operational, SP: Single period, MP: Multiple periods, CM: Cost minimization, PM: Profit maximization, OT: Other objectives.

4.2. Model Characteristics

Model features and product specifications are discussed in this sub-section. Model features are time window constraints, perishability of products, resource limitations, uncertainty, product waste, and sustainability. The number of products and product types are indicated as well. AFSC characteristics are summarized in Table 3.

4.2.1. Model Features

Model features are addressed in detail below. Figure 4 presents the number of articles that consider various problem characteristics.

Time Window

Time window constraints or limitations were applied by several cultivation and harvesting-related papers. Figure 3 shows that 33 papers incorporated time windows into their model. Time windows were used to limit the time periods for planting and harvesting decisions in the planning horizon (e.g., [37,47]). Refs. [23,44] considered time windows determined by decision-makers for olive harvesting and apple harvesting, respectively. Ref. [26] considered different time windows for each apple variety determined according to ripeness. In the case of wine grape harvesting, optimal harvesting dates were taken into account, and a penalty for harvesting outside the optimal dates were included (e.g., [19,21]). Ref. [90] considered time windows for harvesting wheat at farms. Refs. [85,87] took into account planting and harvesting windows that affect vegetable yields because of different weather conditions. Different from other studies, [33] proposed an uncertain harvesting time window. Some papers considered the maturation curve to optimally harvest crops. Maturation curve was used for products such as orange (e.g., [18]), fresh produce (e.g., [42]), and tomatoes (e.g., [82]). Ref. [59] considered early, preferred, and late harvesting periods and considered early and late harvesting costs.

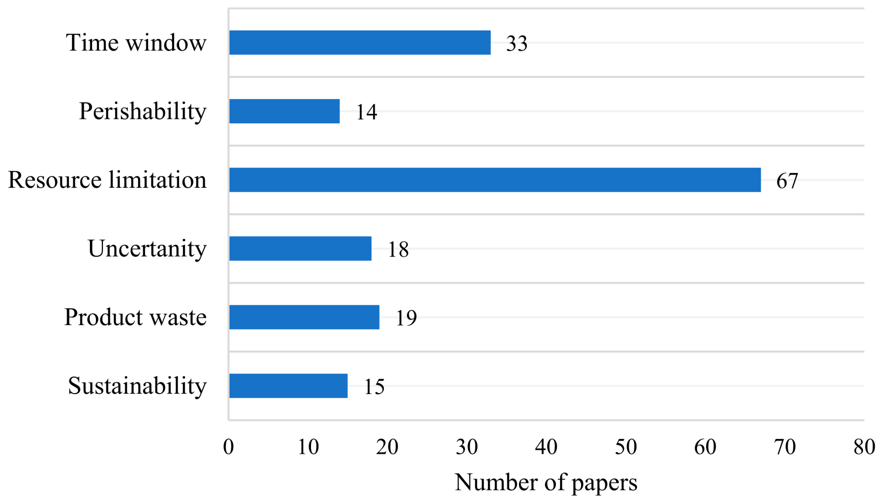

Figure 4. Number of papers regarding problem characteristics.

Perishability

The perishability of agricultural products was discussed in different ways and incorporated into 14 models. Refs. [41,42,65] considered deterioration curves to demonstrate perishability for post-harvest fresh produce. Refs. [77–79,84,88] took into account perishability in terms of color changes throughout the post-harvest periods. Ref. [48] used time-dependent variables and addressed products that can be stock for a certain period of time. Ref. [67] distinguished their research from other studies with the consideration of crop loss at farmers for the entire harvest season. Refs. [84,87] considered shelf-life restrictions. Instead of including quality changes, [69] incorporated different selling prices according to the remaining shelf life. Ref. [71] addressed agri-food deterioration via holding cost function and a fixed deterioration rate. Ref. [89] represented perishability with two alternatives: quality decay factor and shelf-life limitations.

Additionally, some papers took into account crop perishability via model configurations (e.g., [19,44]). Authors designed their problems regarding daily processing capacity; thus, inventory of perishable crops was not allowed, and they assume quality loss did not occur. Due to the lack of specific additions to the models, these types of perishability considerations are not included in Table 3.

Resource Limitation

Almost all of the papers addressed the constraints on limited resources. Most of the papers considered production/processing capacity (e.g., [28,34,72,81]). Some of the cultivation-related papers used available land size as a limitation for planting crops (e.g., [36,48]). Additionally, [57] proposed an uncapacitated and a capacitated model for pea cultivation. Refs. [78,88] considered investment budget for cultivation, on the other hand, [85,87] considered a budget for farming technology selection. In addition, [87] allowed a limited amount of farming operations. Harvesting related papers used multiple different harvesting resources. Harvesting resources with different capacities were taken into account by several papers (e.g., [25,43,44]). Besides that, as a harvesting resource, some papers limited the labor force (e.g., [23,79]). Also, machine availability for harvesting was considered (e.g., [20,22]). Transportation capacity (e.g., [60,64]) and storage capacity (e.g., [50,72]) were included in some papers as well. Supplier capacity for raw materials was taken into account in some papers (e.g., [61,68,75]). Refs. [56,89] differ their study from the literature with the consideration of product selling capacity and production quota for sugar beet, respectively. Ref. [58] consider fuzzy parameters for production, supplier, and warehouse capacity. The distinguishing feature of the model proposed by [39] is the consideration of budget for social corporate responsibility training and improvements.

Uncertainty

Various uncertainty elements of AFSCs were investigated in mathematical models. Crop yield uncertainty was considered in [25,54,59,78,89]. Demand uncertainty was incorporated into the models by [48,89,90]. Refs. [35,53] considered both yield and demand uncertainties in the olive oil and mushroom production industries, respectively. Ref. [52] took into account domestic wheat supply and demand uncertainties. A number of uncertainties were incorporated into few models simultaneously. Ref. [33] took into consideration maturation time, harvest time, crop yield, and demand uncertainties, on the other hand, [72] considered wheat supply, flour demand, transportation cost, and warehouse opening cost uncertainties. Ref. [58] investigated production, supplier, and warehouse capacity, and demand uncertainties. Ref. [40] incorporated fluctuations in agricultural activity costs and sugar content. Ref. [87] considered the variability of rainfall, temperature, and market prices in their study. Market prices were also discussed by [56,78]. Differently from other papers, [20] handled manual harvesting productivity as an uncertain element of the model. Some papers investigated uncertainty in food properties. Refs. [56,80] considered orange juice acidity and olive features, respectively. Ref. [83] analyzed soluble solid content in tomatoes and crop yield uncertainties.

Product Waste

Product waste has been handled in the models since the last decade according to Table 3. Ref. [76] evaluated product wastes for juice production. Ref. [64] considered waste from processing sugar waste. Wax, which is refinery waste from edible vegetable oil, was recycled to use in the cosmetic sector in the study of [58]. If the minimum quality level is exceeded, products would become waste in [65,84,89]. Ref. [67] investigated crop loss percentage due to transportation. Ref. [44] incorporated prominent features of the olive industry by considering olive loss by the severe weather conditions. Post-harvest fresh produce waste was incorporated by [48]. When products exceeded their remaining shelf life, [69] considered them as wastes. When fruit quality level was not enough to sell as packaged fresh fruit due to damages or imperfections, they were considered as wastes and send for juice production [81]. While [71] considered deteriorated products at retailers, [59] considered post-harvest losses during transportation, storage, and processing. Four papers developed a closed-loop supply chain network to recover product wastes. Ref. [34] considered recovering and reusing product waste. Refs. [49–51] considered damaged products as wastes. Ref. [35] considered substrate waste after using it for mushroom cultivation. Ref. [79] took into account product wastes at packing facility, repacking plant, and distribution center due to decay or disorder. Differently, from other studies, [72] considered wheat waste during transportation and minimized it within the social objective function.

Sustainability

In this sub-section, we address the notable interest in the sustainability concept, mostly growing in recent years. Only two articles considered the sustainability concept via constraints. Ref. [48] provided a crop rotation plan with ecological constraints to sustain more productive land. Ref. [73] restricted their model to have a zero-carbon emission ecosystem via constraints. The inclusion of sustainability into the models was done by objective functions in the rest of the papers. Economic and environmental sustainability were considered mostly. Refs. [34,35] considered profit maximization and exergy loss minimization. Ref. [74] focused on global warming potential and minimizing costs, and therefore four objective functions were defined to use in different scenarios. Objective functions are maximizing net present value, minimizing investment, minimizing average variable unit cost, and minimizing CO_2 emissions. Total gross margin and CO_2 emissions of the supply chain were maximized and minimized, respectively in [89]. As an environmental objective, [50] minimized CO_2 emissions sourced by different transportation vehicles which have different CO_2 production rates. Another paper relevant to mention here is that by [72] who consider both total cost and negative impact of social corporate responsibility. The social objective function consists of job opportunities, waste generated during transportation, and loss workdays.

Economic, environmental, and social dimensions of sustainability were taken into account in six models. Ref. [71] minimized total cost and greenhouse gas emissions and maximized public health. Public health objective was indicated as a function of individual health and environmental health. Ref. [60] considered minimizing the total cost, CO_2, and water footprint while maximizing created jobs. Ref. [70] minimized fixed and variable costs and CO_2 emissions from transportation and maximized social impact. Ref. [51] minimized total network costs and CO_2 emissions and maximized demand response. Operational costs and air pollution were minimized, and job creation was maximized in [25]. Ref. [90] minimized network costs and water consumption and maximized job opportunities.

4.2.2. Number of Products

Some articles considered a single product in their models, and the others considered multiple products or multiple different varieties of crops. Also, the concept of multiple products can show variability. 31 articles took into account only one product, whereas 42 articles covered multiple products. Organic and conventional apples by [71]; different sizes of mushrooms by [35]; different packaged olive oil products by [61]; different olive oil combinations by [46]; multiple brands of sugar by [63]; different olive oil qualities by [56] and multiple vegetables by [85] were considered. Some papers considered multiple varieties of crops (e.g., [32,44]). Although [73,79] considered multiple crops, they included only one crop in their case studies.

4.2.3. Agri-Food Types

Fresh product characteristics were considered in 42 articles. Fresh product can be fresh vegetable (e.g., [78]), fresh fruit (e.g., [23]) or grain (e.g., [59]). Processed products were taken into account in 28 articles. For example, orange juice production (e.g., [62]), olive oil production (e.g., [56]), rice processing (e.g., [66]), or tomato processing (e.g., [82]) were considered as processing crops.

Both fresh and processed products were considered by four articles. Ref. [76] studied both fresh and processed fruits. Ref. [67] considered unprocessed and processed soybean products. Ref. [81] handled fruit juice and packaged fresh fruit production. Ref. [84] examined supplying fresh tomatoes to retailers and process facilities. Figure 5 shows the percentage of agri-food types.

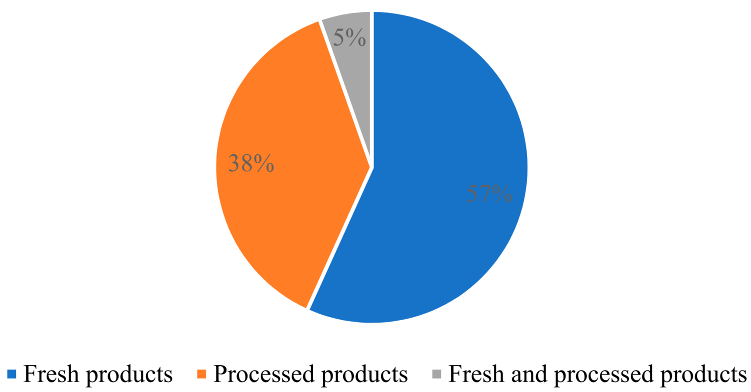

Figure 5. Agri-food types.

Additionally, the products considered are listed in Table 3.

Table 3. Classification according to model characteristics.

Reference	Model Features						No. of Products	Product Type		Product
	TW	PE	RL	UC	PW	SU		Fresh	Processed	
[62]			X				M		X	Orange
[31]	X		X				M	X		Multiple
[53]				X			S		X	Olive
[57]			X				S		X	Pea
[17]	X						S	X		Sugar cane
[18]	X		X				S		X	Orange
[38]			X				S	X		Sugar cane
[63]			X				M		X	Sugar
[41]	X	X					S	X		Unspecified
[47]	X		X				S	X		Sugar cane
[76]	X		X		X		M	X	X	Fruit
[19]	X		X				S	X		Grape
[42]	X	X					S	X		Unspecified
[32]			X				M	X		Sugar cane
[21]	X		X				S	X		Grape
[20]	X		X	X			M	X		Grape
[45]			X				M		X	Olive
[88]	X	X	X				M	X		Vegetable
[77]	X	X	X				M	X		Vegetable
[54]				X			S		X	Olive
[64]			X		X		M		X	Sugarcane
[65]		X	X		X		S	X		Pepper
[78]	X	X	X	X			M	X		Vegetable
[58]			X	X	X		M		X	Edible oil
[27]	X						S	X		Sugarcane
[39]			X				M	X		Vegetable
[33]	X			X			S	X		Tomato
[43]			X				S		X	Sugar cane
[66]			X				M		X	Rice
[48]		X	X	X	X	X	M	X		Vegetable
[80]	X		X	X			M		X	Orange
[40]	X		X	X			S	X		Sugarcane
[23]	X		X				M	X		Apple
[67]		X	X		X		M	X	X	Soybean
[24]			X				S	X		Sugarcane
[36]			X				M	X		Vegetable
[73]			X			X	S	X		Potato
[59]	X		X	X	X		S	X		Grain
[81]	X		X		X		M	X	X	Pome fruit
[82]	X		X				M		X	Tomato
[83]	X		X	X			M		X	Tomato
[34]			X		X	X	M	X		Mushroom
[55]	X		X				M		X	Wine
[84]	X	X	X		X		S	X	X	Tomato
[68]			X				M		X	Wheat
[69]		X	X		X		M	X		Fruit
[44]	X		X			X	M		X	Olive
[74]			X			X	M		X	Orange
[70]			X			X	S		X	Wine
[60]			X			X	M		X	Unspecified
[49]			X		X		S	X		Citrus
[85]	X		X				M	X		Vegetable
[56]			X	X			M		X	Olive
[71]		X	X		X	X	M	X		Apple
[35]			X	X	X	X	M	X		Mushroom
[86]			X				M		X	Rice
[29]	X		X				S	X		Grain
[46]			X				M		X	Olive
[89]		X	X		X	X	M		X	Sugar beet
[28]	X		X				S	X		Sugarcane

Table 3. *Cont.*

Reference	Model Features						No. of Products	Product Type		Product
	TW	PE	RL	UC	PW	SU		Fresh	Processed	
[37]	X		X				M	X		Unspecified
[50]			X		X	X	S	X		Citrus
[79]		X	X		X		S	X		Tomato
[61]			X				M		X	Olive oil
[25]			X	X		X	S	X		Sugarcane
[87]	X	X	X	X			M	X		Vegetable
[26]	X		X				M	X		Apple
[72]			X	X	X	X	S		X	Wheat
[51]			X		X	X	S	X		Fruit
[75]			X				M		X	Rice
[90]			X				S	X		Unspecified
[30]	X		X	X		X	M		X	Wheat
[52]			X	X			S	X		Wheat
[22]	X		X				S	X		Grape

Note: TW: Time window, PE: Perishability, RL: Resource limitation, UC: Uncertainty, PW: Product waste, SU: Sustainability, S: Single product, M: Multiple products.

4.3. Modeling Approach

In this sub-section, mathematical programming models, application types, and solution approaches are discussed, and Table 4 summarizes reviewed papers.

4.3.1. Model Types

We now discuss the optimization modeling types applied to AFSC studies. Predominantly, single-objective optimization was considered by 51 articles, while multi-objective optimization was performed by 21 articles. Different from other studies, only two articles considered bi-level optimization. Figure 6 shows the number of papers according to modeling types. As can be seen from Figure 6, most of the literature is dedicated to deterministic models.

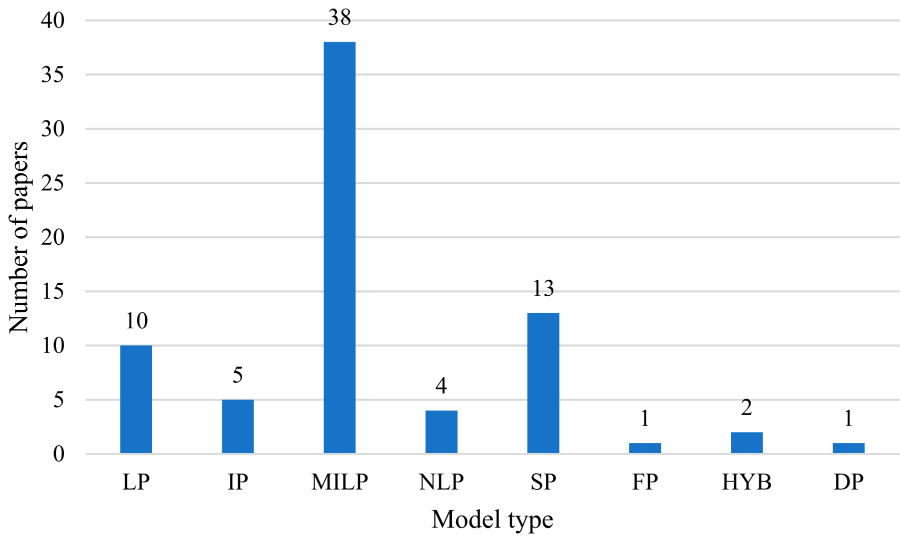

Figure 6. Number of papers according to model types (Note: LP: Linear programming, IP: Integer programming, MILP: Mixed-integer linear programming, NLP: Nonlinear Programming, SP: Stochastic programming, FP: Fuzzy programming HYB: Hybrid, DP: Dynamic programming).

The most preferred modeling type was MILP (e.g., [47,89]). Notably, linear programming and integer programming models are also used in the models. Ref. [17] formulated an integer non-linear programming model to solve harvest scheduling. Ref. [74] presented a pure integer non-linear programming model to design a green AFSC. Ref. [71] proposed a multi-objective mixed-integer non-linear programming model. Bi-level optimization was considered by [59] to provide a robust optimization model and by [86] to model a non-linear programming model.

A number of papers applied the different types of stochastic programming to their models to tackle uncertainties in AFSCs. For example, two-stage stochastic programming by [53]; robust optimization by [20], and scenario-based stochastic programming by [35,52] were considered. Moreover, [83] proposed three robust optimization models to consider uncertain elements individually and simultaneously.

There are only two hybrid models. Ref. [60] developed a multi-criteria method which is an integrated approach of the Analytic Hierarchy Process method and Ordered Weighted Averaging to evaluate stakeholders and use its solution as an input parameter in the mathematical model. Ref. [72] presented a novel hybrid stochastic fuzzy-robust programming, and moreover, four other hybrid approaches were studied.

Ref. [41] used dynamic programming to model a fresh produce supply chain. Ref. [58] proposed a multi-objective fuzzy programming model. Some papers (e.g., [48,89]) also considered the stochastic version of their deterministic models to compare the deterministic and stochastic results.

4.3.2. Data Type

For the validation and illustration of their model, authors used either real case data or hypothetical data. 30 articles demonstrated the validation and practicability of their model with a real case study. Conversely, 44 articles used hypothetical case studies for the illustrations of their model.

4.3.3. Solution Methods

A variety of solution methods have been used to solve AFSC problems. We now discuss the prominent applied solution methods. Solution methodologies are listed in Table 4. Most of the analyzed articles were solved by commercial software such as IBM ILOG (e.g., [44]), GAMS (e.g., [89]), and AMPL (e.g., [79]). Ref. [41] solved their model with an optimization algorithm that consists of decision rules. As an exact solution method, [48] developed a column generation algorithm to solve both deterministic and stochastic models, while [84] solved the mixed-integer problem with a primal Bender's decomposition algorithm.

Several heuristic and meta-heuristic methods were used to solve the considered problems. Ref. [38] solved the transportation planning model with a greedy randomized adaptive search procedure and the harvesting planning model with a tabu search. Ref. [63] used a general version of the tabu search and variable neighborhood search to solve their model. They also compared the metaheuristics. Ref. [19] solved their model in a shorter time by a decomposition heuristic approach than an exact branch and bound algorithm. Ref. [21] proposed two heuristics to solve the scheduling model. Ref. [64] used a decomposition method called rolling horizon. Ref. [27] developed a tabu search approach. Ref. [43] applied a number of solution techniques to solve the large operational planning model. Pre-processing, hot-start construction with heuristic solutions, valid inequalities, and a specialized algorithm were used to solve the model. Ref. [26] developed an algorithm based on a Greedy Randomized Adaptive Search Procedure to find solutions to real cases. Ref. [37] used integer programming-based exact algorithms to solve the problem and proposed a heuristic for large-scale problems. Ref. [30] used an adaptive large neighborhood search algorithm to solve the combinatorial optimization problem.

Refs. [24,55] used heuristics to solve large-scale problems. Ref. [28] solved their model with mixed-integer programming-based heuristic approaches including aggregation process, relax-and-fix constructive heuristic, and fix-and-optimize improvement heuristic. Ref. [29] solved the vehicle routing problem with a memetic algorithm which consists of a genetic algorithm and a local search procedure. Ref. [86] used a genetic algorithm, particle swarm algorithm, and two hybrids of these algorithms. Ref. [50] used a multi-objective version of the tree growth algorithm as the main solution tool and compared the solutions with other evolutionary algorithms.

Several methods were used to solve multi-objective models. Notable solution methods, ϵ-constraint (e.g., [35,89]) and augmented ϵ-constraint method (e.g., [71,81]) were used in several articles. Refs. [46,74] solved their multi-objective model with a Non-Dominated-Sorting-Genetic algorithm. Ref. [74] used a multi-criteria decision-making process to find the best solution. Ref. [69] used the simple additive weighting method to maintain one global objective function. Ref. [51] used LP-Metric and weighted Tchebycheff methods to find Pareto optimal solutions, on the other hand, [25] considered compromise programming. Ref. [90] used simulation to address demand uncertainty and then, considered meta-goal programming to solve a multi-objective model.

Several step solution procedures were applied by [22]. Firstly, initial Pareto optimal solutions are found with the augmented weighted Tchebycheff method. If decision-makers do not accept the initial solution, then, Pareto optimal solutions are found in a local neighborhood through the augmented ε-constraint method. Different from other studies, [60] solved the first stage of the problem by multi-criteria methods. Then, the multi-objective model was solved with an approach based on the ε-constraint method. Ref. [49] developed a new population-based meta-heuristic algorithm called the multi-objective Keshtel algorithm and then compared the solutions with other meta-heuristics. In addition, two articles used goal programming to solve multi-objective optimization ([40,62]).

Some methods were used to solve stochastic programming models. Monte Carlo simulation was used to solve a robust optimization model by [20]. As a different solution technique, [78] used the two-stage stochastic programming, Bender's decomposition, and multi-cut algorithm. Ref. [59] proposed a Lagrangian relaxation algorithm to solve the stochastic model. Ref. [87] used a two-stage stochastic decomposition approach to solve the stochastic model. Ref. [35] used sample average approximation based on Monte Carlo simulation to find better solutions. Moreover, [33] solved their model with exact and approximate solutions and compared them.

Table 4. Classification according to modeling approach.

Reference	Model Type				Data Type	Solution Methods
	SO	MO	BL			
[62]		X		LP	HP	Goal programming
[31]	X			MILP	HP	Exact
[53]	X			SP	HP	Exact
[57]	X			LP	HP	Exact
[17]	X			NLP	RC	Exact
[18]	X			LP	RC	Exact
[38]	X			IP	RC	Metaheuristics
[63]	X			MILP	HP	Metaheuristics
[41]	X			DP	HP	Exact
[47]	X			MILP	RC	Exact
[76]	X			LP	HP	Exact
[19]	X			MILP	RC	Heuristics
[42]	X			MILP	HP	Exact
[32]	X			LP	HP	Exact
[21]	X			MILP	HP	Heuristics
[20]	X			SP	RC	Simulation
[45]	X			MILP	HP	Heuristics
[88]	X			MILP	HP	Exact
[77]	X			MILP	HP	Exact
[54]	X			SP	HP	Exact
[64]	X			MILP	HP	Heuristic
[65]	X			MILP	HP	Exact
[78]	X			SP	HP	Exact
[58]		X		FP	RC	Exact

Table 4. *Cont.*

Reference	Model Type				Data Type	Solution Methods
	SO	MO	BL			
[27]	X			IP	RC	Metaheuristic
[39]		X		MILP	HP	Exact
[33]	X			SP	HP	Approximate/Exact
[43]	X			MILP	HP	Heuristic
[66]	X			MILP	HP	Exact
[48]	X			LP	HP	Exact
[80]	X			SP	HP	Exact
[40]		X		LP	RC	Goal programming
[23]	X			MILP	RC	Exact
[67]	X			LP	RC	Exact
[24]	X			MILP	RC	Heuristic
[36]	X			MILP	HP	Exact
[73]	X			LP	HP	Exact
[59]			X	SP	HP	Heuristic
[81]		X		MILP	HP	Augmented ε-constraint
[82]	X			LP	RC	Exact
[83]	X			SP	RC	Exact
[34]		X		MILP	RC	ε-constraint
[55]	X			MILP	HP	Heuristic
[84]	X			MILP	RC	Exact
[68]	X			MILP	RC	Exact
[69]		X		MILP	RC	MCDM
[44]	X			MILP	RC	Exact
[74]		X		NLP	HP	Metaheuristics +MCDM
[70]		X		MILP	RC	Augmented ε-constraint
[60]		X		HYB	HP	Exact
[49]		X		MILP	HP	Metaheuristics
[85]	X			MILP	HP	Exact
[56]	X			SP	HP	Exact
[71]		X		NLP	RC	Augmented ε-constraint
[35]		X		SP	RC	ε-constraint + simulation
[86]			X	NLP	HP	Metaheuristics
[29]	X			MILP	HP	Heuristic
[46]		X		MILP	HP	Metaheuristic
[89]		X		MILP	HP	ε-constraint
[28]	X			MILP	RC	Heuristic
[37]	X			IP	HP	Heuristic
[50]		X		MILP	HP	Metaheuristics
[79]	X			MILP	HP	Exact
[61]	X			IP	RC	Exact
[25]		X		SP	RC	Compromise programming
[87]	X			SP	HP	Exact
[26]	X			MILP	RC	Metaheuristic
[72]		X		HYB	RC	Compromise programming
[51]		X		MILP	HP	LP-Metric + weighted Tchebycheff method
[75]				MILP	RC	Exact
[90]	X			IP	HP	Metaheuristic
[30]		X		MILP	RC	Simulation + Meta-goal programming
[52]	X			SP	RC	Exact
[22]		X		MILP	HP	Heuristic + augmented ε-constraint

Note: SO: Single-objective optimization, MO: Multi-objective optimization, BL: Bi-level optimization, LP: Linear programming, IP: Integer programming, MILP: Mixed-integer linear programming, SP: Stochastic programming, SM: Simulation, HYB: Hybrid, DP: Dynamic programming, FP: Fuzzy programming, RC: Real case, HP: Hypothetical, MCDM: Multi-criteria decision-making.

5. Findings and Future Research Directions

In this section, based on the above insights already observed in the previous section, we discuss the results deduced from the presented literature review study and propose research directions that need greater investigation. The topics discussed are shown in Figure 7.

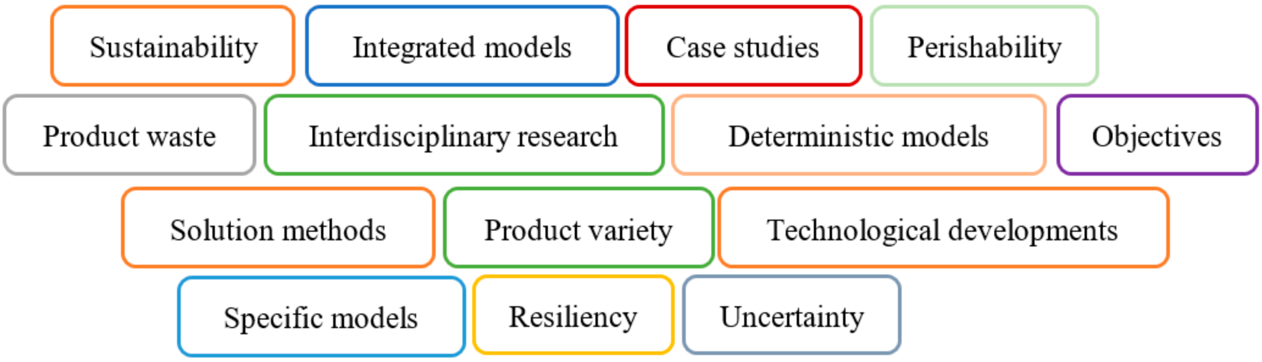

Figure 7. Topics discussed.

After revising 74 papers published in a 20-year period regarding the harvest and production planning, we now discuss review results. Papers published from 2000 to 2010 are very few than papers published from 2010 to 2020. In the last decade, there is increasing attention to addressing AFSC optimization models. Model configurations and included characteristics have been changed over the years. From the Tables, we observe some trends in the research area. As a result of interest in sustainability, it has been incorporated in AFSC optimization models more recently. Concerning the decisions to make integrated decision problems have become even more popular in recent years. Stochastic, robust solution methodologies have been used more frequently in the last decade to handle uncertain parameters.

- There are only a few papers that include several decision variables and thus have a broader perspective in the AFCS context (e.g., [88]). However, the vast majority of the models focused on certain parts of the supply chain. For instance, these parts can be harvesting (e.g., [19]) or production and distribution (e.g., [65]). Therefore, integrated supply chain designs are needed to make more efficient and effective decision-making processes. In line with the argument above, although previous reviews (e.g., [2,3] strongly emphasize the lack of integrated harvest and production models, still very few articles exist on the subject. It is necessary to develop integrated harvesting and production models coordinating harvest fields and production facilities.
- We can conclude that most of the agricultural crops and products have different characteristics. For example, tomatoes and peppers need different handling and storage conditions than apples. Orange juice, as well as olive oil production, have different processing requirements, such as the timing of the processing crops to obtain the required quality and quantity. Hence, there is a need to develop specific models for AFSCs rather than generic models.
- Few studies address product waste [48,69] which can occur in the supply chain because of the inherent characteristics of agri-foods. Future research of incorporating product waste is a crucial contribution to the literature.
- One aspect that is also neglected to a large extent in the literature is considering multiple product varieties. Optimization models in AFSCs should include product variety and heterogeneity to explore real-world complexities.
- AFSCs are associated with several different topics. To exemplify, these topics can be economics, cultivation, geography, climate, food engineering, and logistics. So, interdisciplinary research approaches can be very useful for efficient and more specific supply chain design.
- Although in recent years sustainability has gained more interest by the academia (e.g., [50,90]), there still exists the need for developing and modeling sustainable AFSCs.
- In contrast to the vast body of the literature dedicated to the fresh product supply chain, there has been relatively less attention to the perishability. Perishability is one of the prominent features of fresh products, therefore incorporating perishability into the models would make them more comprehensive.

- The vast majority of the papers use deterministic models and few papers consider uncertainty. Therefore, incorporating uncertain elements into the AFSC models is a promising research area.
- Relatively fewer papers validated the model with real-life case studies. More studies are needed to implement real data sets to validate the applicability of the models.
- Exact solution methodologies are mostly used to solve optimization models (e.g., [61,85]. Although heuristic and metaheuristic methods have been used in recent years [30,86], there is a need to develop new heuristics, mat-heuristics, or/and hybrid solution methodologies that combine different perspectives and taking advantage of both to solve the real size AFSC problems.
- Although some previous review studies point out the need for resiliency in AFSC studies, only one paper [72] included this concept in their model, and resiliency is a new and unexplored area of research. There is an urgent need to consider resilience strategies in the AFSC literature.
- Farmer and producer collaborations can contribute to developing models that contain real-life problem complexities. Therefore, collaboration among the stakeholders of AFSC with academia may lead to a greater development of applied research.
- Remarkably, most of the reviewed literature considers economic objectives (cost minimization and profit maximization). It can be beneficial to investigate AFSCs thoroughly to include more specific objectives such as maximizing product quality, minimizing product waste, and minimizing energy usage.
- Recent developments in technology can create new opportunities for AFSC actors [14]. Integrating digital technologies such as big data, the internet of things, and sensor technologies have numerous potential research topics.

6. Conclusions

This review paper presents a systematic literature review of optimization models of harvest and production planning in AFSCs. Based on previous review studies, a classification scheme was developed to conduct a systematic review. This review analyzes and classifies the selected papers according to problem scope, model characteristics, and modeling approaches, to clearly show the gaps in the literature and determine research opportunities and future research directions. We answered the research questions mentioned in this paper. The results of our study can provide benefits for practitioners and academicians working on agri-food. The main conclusions are the need for more studies on integrated decisions in AFSC, and the need for a closer relationship between academia and stakeholders to generate more applied research. Although many research papers address optimization models in AFSC, still there is a need to incorporate new methodologies in the field of agriculture.

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Appendix A

Reference	Journal	Country
[62]	Operational Research Society of India	Brazil
[31]	Production, Manufacturing and Logistics	Spain
[53]	Manufacturing & Service Operations Management	USA
[57]	Journal of Food Engineering	The Netherlands
[17]	Computers and Electronics in Agriculture	Australia
[18]	Journal of the Operational Research Society	Brazil
[38]	Journal of the Operational Research Society	Australia
[63]	Journal of the Operational Research Society	Australia
[41]	European Journal of Operational Research	Japan
[47]	International Journal of Production Economics	Multiple
[76]	Book chapter: Process Systems Engineering: Supply Chain Optimization. Part II	Argentina
[19]	International Journal of Production Economics	Chile
[42]	Journal of the Operations Research Society of Japan	Japan
[32]	Agricultural Systems	Thailand
[21]	International Transactions in Operational Research	Lebanon
[20]	European Journal of Operational Research	Chile
[45]	Croatian Operational Research Review	Croatia
[88]	Annals of Operations Research	USA
[77]	International Journal of Production Economics	USA
[54]	Manufacturing & Service Operations Management	USA
[64]	Computers and Chemical Engineering	Multiple
[65]	International Journal of Production Economics	Multiple
[78]	Agricultural Systems	USA
[58]	Applied Mathematical Modelling	Turkey
[27]	Computers and Electronics in Agriculture	South Africa
[39]	Makara Journal of Technology	Indonesia
[33]	European Journal of Operational Research	Turkey
[43]	European Journal of Operational Research	Brazil
[66]	Computers and Chemical Engineering	Malaysia
[48]	Annals of Operations Research	Brazil
[80]	Computers and Electronics in Agriculture	Brazil
[40]	Applied Mathematical Modelling	Brazil
[23]	Book chapter -Handbook of Operations Research in Agriculture and the Agri-Food Industry	Chile
[67]	Journal of Transport Geography	Brazil
[24]	Computers and Electronics in Agriculture	Thailand
[36]	International Journal of Production Economics	USA
[73]	Journal of Cleaner Production	Multiple
[59]	Transportation Research Part E	USA
[81]	Computers and Electronics in Agriculture	Argentina

Reference	Journal	Country
[82]	Computers and Electronics in Agriculture	Brazil
[83]	International Journal of Production Research	Brazil
[34]	International Journal of Production Economics	The Netherlands
[55]	Computers & Industrial Engineering	Chile
[84]	Central European Journal of Operations Research	Iran
[68]	Computers and Electronics in Agriculture	Iran
[69]	Applied Mathematical Modelling	Spain
[44]	Computers and Electronics in Agriculture	Chile
[74]	Computers & Industrial Engineering	Multiple
[70]	Omega	Australia
[60]	Computers and Operations Research	Multiple
[49]	Applied Soft Computing	Iran
[85]	Agricultural Systems	USA
[56]	Journal of Process Control	Spain
[71]	Journal of Cleaner Production	Multiple
[35]	Journal of Cleaner Production	The Netherlands
[86]	Computers and Electronics in Agriculture	Iran
[29]	Applied Soft Computing	China
[46]	Ekonomski Vjesnik	Croatia
[89]	European Journal of Operational Research	Multiple
[28]	International Journal of Production Economics	Brazil
[37]	Artificial Intelligence in Agriculture	-
[50]	Journal of Cleaner Production	Iran
[79]	Postharvest Biology and Technology	USA
[61]	International Journal of Sustainable Agricultural Management and Informatics	Multiple
[25]	Journal of Cleaner Production	Multiple
[87]	European Journal of Operational Research	USA
[26]	European Journal of Operational Research	Chile
[72]	Computers and Electronics in Agriculture	Iran
[51]	Management of Environmental Quality	Multiple
[75]	Decision Science Letters	Iran
[90]	Computers and Electronics in Agriculture	Multiple
[30]	Computers and Electronics in Agriculture	Iran
[52]	Decision Science Letters	Iran
[22]	Computers & Industrial Engineering	Chile

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