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The Current Trends of Research on Mathematical Programming Models for Perishable Fresh Produce Supply Chain: A Thematic Review

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Abstract

Fruits and vegetables are perishable agricultural produce that are in high demand across the world as sources of food for daily and industrial needs. There has been a vast interest in perishable fresh produce as they have a short shelf life and their freshness needs to be maintained. There have been studies concerning the post-harvest supply chain, fresh produce's shelf-life maximization, preserving freshness and quality, and reducing spoilage of these fresh produce. However, studies on the development of mathematical programming (MP) models for fresh produce freshness and shelf-life optimization are still limited. This paper presents a review of past studies from journals and proceeding papers between 2018 and 2023 using a thematic review approach on MP models of fresh produce supply chain. These papers were analyzed using thematic analysis ATLAS.ti.22 software by using keyword search and filtering criteria from Scopus and the Web of Science (WOS) databases. After the exclusion and inclusion processes, only 25 articles were selected as final articles to be reviewed. The thematic review was organized according to five main themes: distribution management, inventory management, logistics management, production management, and sustainability. The report from code-to-document in ATLAS.ti 22 identified the three main criteria: model's objective(s), type of MP model, and solution method, which were highlighted in the literature. Findings presented in this paper provide relevant insights for the establishment and applications of MP models in studies on fresh produce's shelf-life and freshness maximization and the development of optimal strategies for managing the fresh produce supply chain which is crucial for sustainability.

Keywords: Agriculture Supply Chain, ATLAS.ti 22, Mathematical Programming Models, Perishable Fresh Produce, Thematic Review

Introduction

There is a growing awareness of the importance of maintaining the quality of perishable products in supply chains (Tort et al., 2022). Furthermore, the Food and Agriculture Organisation announced that the UN General Assembly has designated 2021 as the International Year of Fruits and Vegetables (IYFV). The International Year of Fruits and Vegetables (IYFV) is an extraordinary chance to raise awareness of the critical role of fruits and vegetables in human nutrition, food security, and health, as well as in achieving the UN Sustainable Development Goals (FA0, 2020). Perishable products, also known as products with limited shelf life, can quickly spoil or become unsafe for consumption and usage if they are not stored or handled properly (Alipour et al., 2020). Examples of perishable products include agricultural products such as fresh produce (fruits and vegetables), dairy, poultry, and frozen or processed foods, commodities like cosmetics, health care products like medicines, oxygens, and lifesaving items such as blood (Sakhare & Kulkarni, 2022). Preserving the quality of perishable products is crucial for food safety and security, and gaining more attention due to growing concerns about food quality, healthcare, and quality of life (Wang et al., 2019). According to Aghaei Fishani et al (2022), among the most important parts of supply chain management is to design the supply chain network of perishable products. Concerns over fresh produce post-harvest supply chain, preserving freshness, maximizing shelf-life, reducing spoilage, and maintaining quality have attracted many studies. However, not much consideration was given on the development of mathematical programming (MP) models for fresh produce freshness and shelf-life optimization. Our study concerns with optimization of transportation costs and freshness in fresh produce supply chain using multi-objective MP models. Despite some studies have been conducted involving MP models on perishable produce supply chain, review papers on them are limited. Thus, this paper presents a thematic review on the current trends in research concerning the perishable fresh produce supply chain, especially those involving MP models. Discussions include topics related to the main features of MP models such as types, objective function(s), and solution methods for solving the models. The research question addressed by this paper is as follows: “What are the current trends of the MP models employed by studies on perishable products supply chain for the last six years, 2018-2023?”.

Material and Methodology

This paper discusses in detail materials and methods for the thematic review which mainly concerns with thematic analysis. Clarke and Braun (2013) defined thematic analysis as a process of identifying the pattern and constructing themes over thorough reading on the subject. The basic approach of thematic analysis is to compare and contrast certain approaches with other approaches, where relevant. In addition, rigorous thematic analysis can produce trustworthy and insightful findings (Braun & Clarke, 2006). Even though there are various approaches in conducting thematic analysis, the most common steps involve a six-step process namely: i) familiarization, ii) coding, iii) generating themes, iv) reviewing themes, v) defining and naming themes, and vi) writing up.

By implementing thematic reviews on past studies, we are able to identify the patterns and construct the categories related to current trends in the MP models employed by studies on the fresh produce supply chain. The aim is to generate a comprehensive thematic analysis

that allows us to determine the main themes, interpret findings, utilize vital information, and share the findings which can benefit some other current and future research on the MP models of perishable fresh produce supply chain. Selection of literature was performed according to several criteria: i) publications from 2018-2023, ii) publications from Scopus and WOS databases, and iii) have at least the keywords “mathematical model” and “perishable product”. The decision on using these keywords was made to focus on issues and problems in perishable produce supply chain and to identify the criteria of MP models proposed.

The literature search was performed in the Scopus and Web of Science (WOS) databases, as illustrated in Table 1. The inclusion and exclusion criteria are carried out, as displayed in Figure 1. The initial search came out with 136 articles from (SCOPUS) and 71 (WOS) articles. However, 111 articles were removed due to their premature results and anecdotes or were not discussed. Some of the articles were also found to be incomplete, or were not fully accessible, and had broken links while ten overlapped articles and those with incomplete metadata have also been excluded. Therefore, the final articles included for the reviews are down to 25 articles including conference proceedings and journals. Besides that, only articles in English were selected. The articles were uploaded in ATLAS.ti 22 as primary documents and grouped based on the following categories: 1) author(s); 2) issue number; 3) periodical, 4) publisher, 5) volume, and 6) year of publication. In doing so, the articles can be analyzed according to the year it was published and its discussion pattern according to the year. The classification of the final documents in the ATLAS.ti 22 for the 25 articles is shown in Figure 2.

Table 1
Search Strings from Scopus and WOS

Source	**Keywords**	**Results**
SCOPUS	TITLE-ABS-KEY (mathematical AND model AND perishable AND product) AND (LIMIT-TO (PUBYEAR, 2023) OR LIMIT-TO (PUBYEAR, 2022) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2019) OR LIMIT-TO (PUBYEAR, 2018)) AND (LIMIT-TO (LANGUAGE, "English"))	136 articles 46-open access articles
WOS	TITLE-ABS-KEY (mathematical models AND perishable products)	71 articles

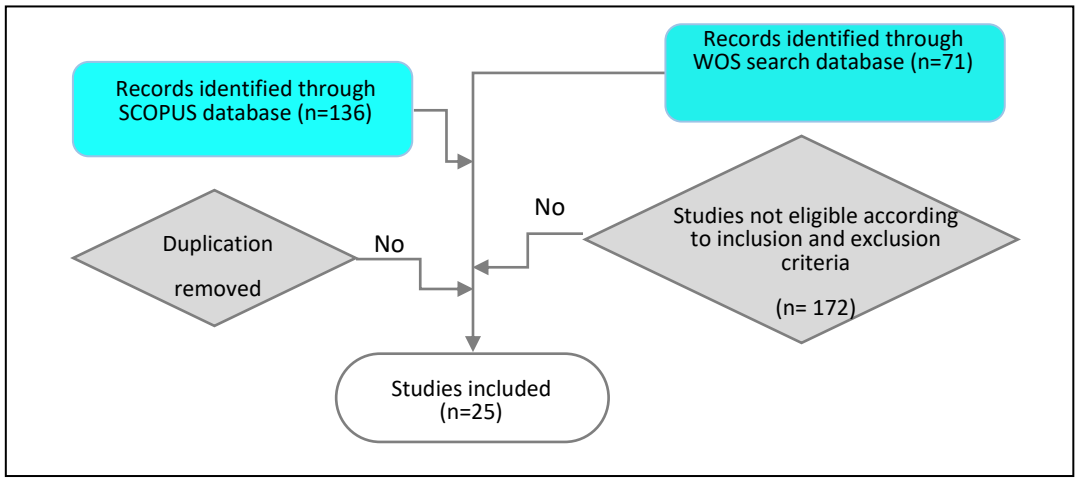

Figure 1: Inclusion and Exclusion Criteria for Identifying Articles for Thematic Review Adapted based on Zairul (2020)

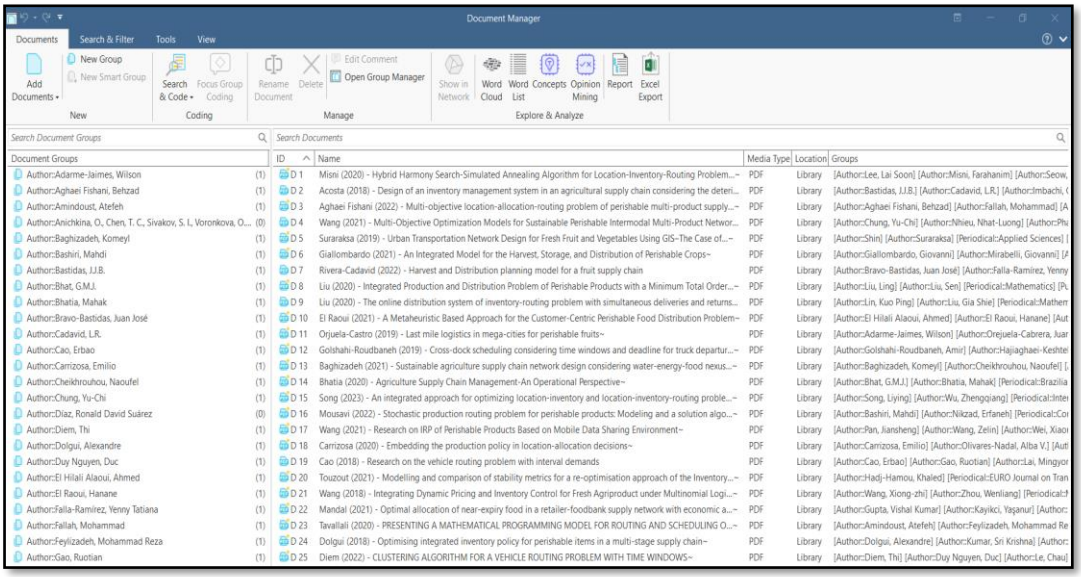

Figure 2: Metadata Extracted from Mendeley and Process in ATLAS.ti 22

Past Studies on MP Models of Fresh Produce Supply Chain

In this section, tables and figures are displayed based on the following subject: journals and year, authors and themes, themes and year, and country and year. In the first step, these research strings are directly referenced with identified 25 articles through several journals listed in Table 2. Two journals' publications have been published in the main domain of mathematical models, notably the Brazilian Journal of Operations and Production Management and Mathematics journal. The trends of publication performed in a normal distribution. The trends shown in publications regarding transportation and technology views have received attention among the authors over the period.

Table 2
Number of Reviewed Articles based on Journals and Year

Journals	Year					
	2018	**2019**	**2020**	**2021**	**2022**	**2023**
4OR			1			
Applied Mathematical Modelling	1					
Applied Sciences		1	1	1		
Brazilian Journal of Operations & Production Management			1			
Computers & Operations Research					1	
Concurrency and Computation: Practice and Experience					1	
Electronics				1		
EURO Journal on Transportation and Logistics				1		
International Journal of Cognitive Informatics and Natural Intelligence				1		
International Journal of Production Research	1					
International Journal of Transportation Science and Technology						1
Journal of Applied Engineering Science	1					
Journal of Cleaner Production				1		
Journal of Industrial Engineering and Management		1				
Mathematical Problems in Engineering	1					
Mathematics			2	1		
Natural Resource Modeling				1		
Polish Journal of Management Studies			1			
Revista UIS Ingenierías					1	
Scientia Iranica		1				
Transport					1	
Total	**4**	**3**	**6**	**7**	**4**	**1**

Figure 3 illustrates the overview of the association of perishable fresh produce and MP models, which were identified in the thematic review based on the five themes of distribution management, inventory management, logistics management, production management, and sustainability. All the themes concern with MP models that emphasized on the models' objective(s), the types of MP models used to achieve those objective(s), and solution methods applied by authors. Meanwhile, Figure 4 demonstrates sustainability network as one of the themes and its thematic analysis using ATLAS.ti for three main criteria: model objectives, type of MP models, and solution methods used.

Table 3
Categories of Articles based on Themes

References	Distribution	Inventory	Logistics	Production	Sustainability
Cao et al (2018)	√				
Dolgui et al (2018)	√	√		√	
Acosta et al (2018)		√			
Wang and Zhou (2018)		√			
Golshahi-Roudbaneh et al (2019)	√		√		
Orjuela-Castro et al (2019)	√		√		
Suraraksa and Shin (2019)	√		√		
Bhatia and Bhat (2020)	√			√	
Carrizosa et al (2020)				√	
Liu and Lin (2020)	√	√			
Misni et al (2020)		√	√		
Liu and Liu (2020)	√			√	
Tavallali et al (2020)	√		√		
Baghizadeh et al (2021)					√
El Raoui et al (2021)	√				
Giallombardo et al (2021)	√	√			
Mandal et al (2021)	√		√		
Touzout et al (2021)	√	√			
Nhieu et al (2021)	√		√		√
Wei et al (2021)	√	√			
Fishani et al (2022)	√		√		√
Le et al (2022)	√		√		
Mousavi et al (2022)	√	√		√	
Rivera-Cadavid et al (2022)	√				
Song and Wu (2023)	√	√			
Total	**20**	**10**	**9**	**5**	**3**

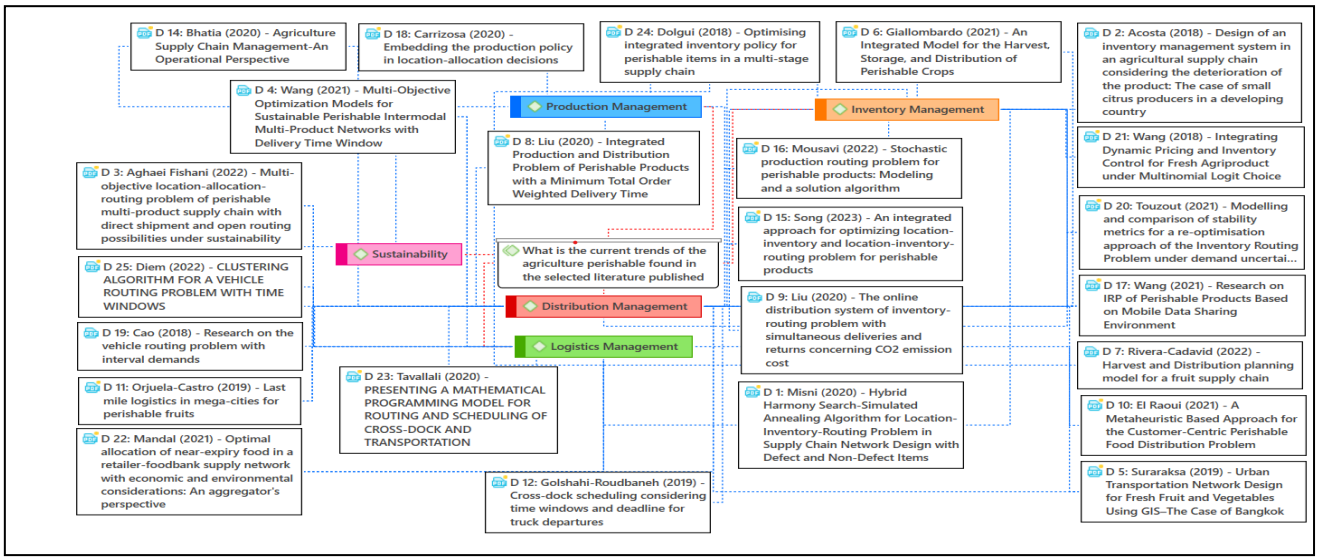

Figure 3: Overall Network for Perishable Products on Mathematical Models

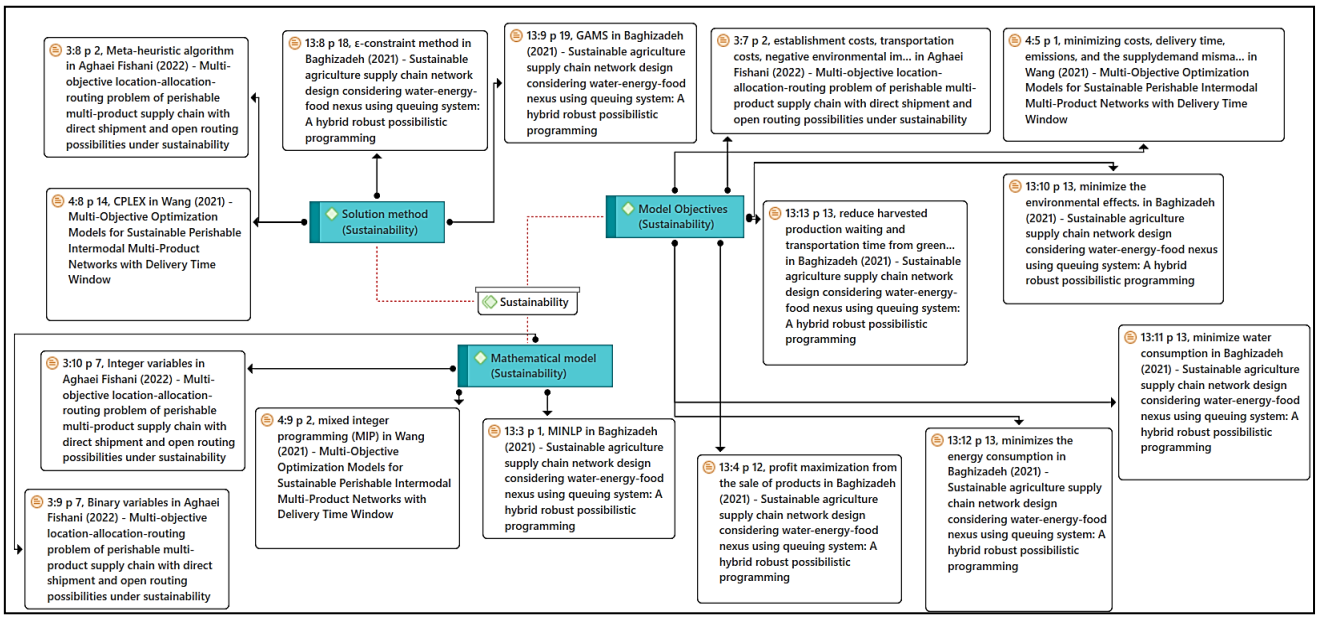

Figure 4: Sustainability Network

The discussion of the thematic review concerning perishable products and MP models of past studies is summarized in Table 4. Integrating the term "supply chain" got high attention among the authors across the years 2018-2023. Mousavi et al (2022) state that integrating supply chain decisions has a key role in the effective supply chain management of fresh produce. Few authors have also incorporated distribution, logistics, and sustainability in their studies (Fishani et al., 2022; Nhieu, et al., 2021). Meanwhile, distribution, inventory, and production were merged to generate an effective perishable product supply chain (Dolgui et al., 2018; Mousavi et al., 2022).

The objective of the MP model or known as objective function is a function of a set of decision variables that assesses the quality of solutions for a given criterion. The decision-maker generally chooses the optimum solution by minimizing or maximizing the function (MirHassani & Hooshmand, 2019). The objective function consists of single, dual (bi-objective), or multiple objectives (multi-objective). The analysis of the model's objective(s)

shows that existing literature has predominantly focused on minimizing costs. For instance, Golshahi-Roudbaneh et al (2021) looked at minimizing total costs resulting from the tardiness and earliness of shipping trucks. The second most significant objective function proposed by past studies was to minimize transportation costs (Fishani et al., 2022; Tavallali et al., 2020). Throughout the period, there was a positive trend of authors to cover three main pillars or TBL of sustainability into the MP models. Fishani et al (2022) incorporated the objective functions of minimizing costs, transportation costs, negative environmental impacts, and social impact (fixed and variable employment rates) as objective functions of the model.

Besides, the concern about reducing the carbon emissions have increased over the recent years Mandal et al (2021); Wang et al (2021), followed by maximizing profits (Bhatia & Janardhana, 2020; Caballero & Rivera, 2019; Giallombardo et al., 2021; Mandal et al., 2021). Suraraksa and Shin (2019) have developed bi- and multi-objectives MP models to have a more effective model with the aim which are: to minimize the number of facilities, to minimize the weighted sum of covered demand nodes, to minimize number of vehicles used, and to minimize the travel costs. Meanwhile, El Raoui et al (2018) proposed a multi-objective MP model which concerns with maximizing freshness, maximizing service level, and minimizing the total costs. Thus, there is still a lack of studies that address the maximization of the perishable products' freshness and the minimization of the perishable products' waste, which can occur in the supply chain. Hence, future research should consider integrating perishable products' freshness and perishable products' waste optimization as MP models' objectives.

Table 4
Summary of Thematic Review Perishable Products on Mathematical Model

Reference	**Theme**	**Objective Function of MP Model**	**Type of MP Model**	**Solution Method**	**Dimension of Sustainability**
Cao et al (2018)	D	Minimize Cost	NLIBSP	MATLAB	Economy
Dolgui et al (2018)	D-I-P	Minimize Cost	MIP	CPLEX	Economy
Acosta et al (2018)	I	Minimize Cost	MP	MATLAB	Economy
Wang and Zhou (2018)	I	Maximize Profit	SDP	MATLAB	Economy
Golshahi-Roudbaneh et al (2019)	D-L	Minimize Cost	MIP	HS-SA	Economy
Orjuela-Castro et al (2019)	D-L	Minimize Vehicle and Travel Costs	MIP	AMPL, Gurobi Solver	Economy
Suraraksa and Shin (2019)	D-L	Minimize Facilities Used Minimize Travel Costs	MIP	GIS	Economy
Bhatia and Bhat (2020)	D-P	Maximize Profit	LP	LINGO	Economy
Carrizosa et al (2020)	P	Maximize Profit	MIP	Xpress	Economy

Misni et al (2020)	I-L	Minimize (Min.) Cost	MILP	HS-SA	Economy (Eco)
Liu and Lin (2020)	D-I	Min. Inventory Routing Costs	MIP	Heuristic	Economy
Liu and Liu (2020)	D-P	Maximize Total Weighted Delivery	LP	CPLEX	Economy
Tavallali et al (2020)	D-L	Minimize Cost Maximize Profit	MILP	NGSA II	Economy
Baghizadeh et al (2021)	S	Maximize Profit	MINLP	ε-constraint GAMS	Economy
El Raoui et al (2021)	D	Min. Cost; Max. Freshness; Maximize Service level	MIP	GVNS	Economy Social
Giallombardo et al (2021)	D-I	Maximize (Max.) Profit Minimize Routing Costs	MIP	CPLEX	Economy
Mandal et al (2021)	D-L	Maximize Profit Min. Env. Impact	MILP	CPLEX	Economy Environment
Touzout et al (2021)	D-I	Minimize Cost	MILP	Branch-and-cut algorithm	Economy
Nhieu et al (2021)	D-L-S	Minimize Cost Min. Env. Impact	MIP	CPLEX	Economy Environment
Wei et al (2021)	D-I	Minimize Cost	MILP	IDE	Economy
Fishani et al (2022)	D-L-S	Min. Cost; Min. Social Impact; Min. Environment (Env.) Impact	MILP	Metaheuristic	Economy-Social-Environment
Le et al (2022)	D-L	Minimize Labour and Travel Costs	MIP	Branch and-cut algorithm	Economy Social
Mousavi et al (2022)	D-I-P	Minimize Cost	MIP	CLPEX	Economy
Rivera-Cadavid et al (2022)	D	Maximize Profit	MIP	AMPL, CPLEX	Economy
Song and Wu (2023)	D-I	Minimize Cost	MINLP, MILP	CPLEX, SA	Economy

I: Inventory, D: Distribution, L: Logistics, P: Production, S: Sustainability, MIP: Mixed Integer Programming, MILP: Mixed Integer Linear Programming, MINLP: Mixed Integer Non-Linear Programming, LP: Linear Programming, NLIBSP: Nonlinear Interval-Based programming, SDP:

Stochastic Dynamic Programming, HS-SA: Hybrid Harmony Search-Simulated Annealing, GVNS: General Variable Neighbourhood Search, SA: Simulated Annealing, NGSA II: Non-Dominated Sorting Genetic Algorithm-II, Eco: Economic

Next, the analysis on the MP models looked at the models' formulation where decision variables, parameters, and input variables are presented in the form of mathematical equalities and inequalities for the constraints which provide the feasible region or the set of acceptable solution alternatives and choices for the right decision. Finally, in the stage of model solving, the appropriate solution method for solving the MP model is employed to determine the optimum solution. Based on the thematic analysis, it is found that most studies have chosen the mixed integer programming (MIP) models which suit most of the real-life problems by involving decision variables whose values include a mixture of real numbers, integers, and binary integers, regardless of whether they are using real data, simulated data, or benchmark instances. However, few authors have also formulated the problems using the traditional LP model (Bhatia & Bhat, 2020; Liu and Liu, 2020).

Several methods were used to solve the MP models. Most of the MP models were solved using approximate methods which include heuristics and metaheuristics algorithms that find near-optimal solutions within reasonable computation time for large-size problems instead of using exact methods that find globally optimal solutions but suffer from long computational time for large instances. Nowadays, there have been many optimization solvers available as solution methods such as the Excel Solver and MATLAB Optimization ToolBox. Based on Table 4, mathematical programming (MP) and optimization modeling languages such as MATLAB, CPLEX, AMPL, and LINGO have been used to solve the optimization models of past studies. Some of the past studies listed in Table 4 have also developed metaheuristics algorithms such as SA, HS-SA, GVNS, and NGSA II. However, only Suraraksa and Shin (2019) have used digital technology deployment to find the solutions to the model. The use of digital technologies such as big data, the internet of things, and sensor technologies can also be used to optimize the operations in the perishable products supply chain (Taşkıner & Bilgen, 2021). In recent years the incorporation of the three dimensions of sustainability (economic, social, and environmental) has gained more attention. Hence, the capability of formulating the appropriate and more effective MP models to solve the problems in perishable fresh produce supply chain has become more critical where, respectively, suitable solution methods must be developed to optimize the models.

Conclusions

This study reviews the patterns and trends of research on the perishable fresh produce supply chain using MP models to generate new research ideas. ATLAS.ti 22's code-to-document analysis reveals that the patterns and trends in perishable fresh produce involve the incorporation of supply chain-enhancing themes. Throughout the six years involved in this review, sustainability has obtained the highest rank among the themes discussed on MP models for the fresh produce supply chain. Moreover, MP models are indispensable tools for conquering challenges by identifying the optimal solution among several alternatives. This paper explores the research trends concerning the fresh produce supply chain by further specifying the thematic codes within the MP models (objective(s), type, and solution methods) involved to assess the models' latest trends. Based on this thematic review's findings, majority of authors chose the MIP model paradigm for handling complex problems. Furthermore, trends toward the incorporation of several objectives are required to solve substantial real-world issues. Moreover, research gaps in fresh produce freshness and waste

should be addressed to contribute towards achieving the United Nations Sustainable Development Goals (SDGs) namely SDG 12, Target 12.3, "By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses". Contribution-wise, this review paper promotes the development of prospective new MP models for future studies on perishable fresh produce supply chains that can fill the research gaps highlighted by this paper.

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