



Article

Multitiered Fresh Produce Supply Chain: The Case of Tomatoes

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Abstract: The United States is one of the world's top producers of fresh tomatoes. However, the industry supply chain is not well understood with little attention in the literature. To attend to this literature gap and to better inform business decisions and policy making, it is crucial to understand the industry structure on a deeper level. Applying a supply chain mapping approach, this study presents a complete picture of the U.S. fresh tomato supply chain with valuable insights into the fresh produce industry and lays the groundwork for future research on solving supply chain issues.

Keywords: supply chain; fruit and vegetables; fresh tomatoes; marketing; trade; labor



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1. Introduction

Tomatoes, a crop with a high nutritional value and one of the most consumed vegetables in the world, play a vital part in the global food system [1]. The United States is one of the world's top producers of fresh tomatoes. With 0.97 million metric tons of production valued at \$1 billion USD in 2021, fresh tomato is the highest-valued crop among all fresh vegetables grown in the United States [2]. U.S. fresh tomato consumption has held relatively steady over the past two decades at about 9 kilograms (kgs) per capita [2]. However, U.S. fresh tomato production fell from 1.89 million metric tons in 2000 to 0.97 million metric tons in 2021, with open-field production experiencing a sharper decrease [2].

In 2021, the total supply of fresh tomatoes in the United States was 2.9 million metric tons, with domestic production accounting for 33% of the total supply, dropping to half of what it was twenty years ago [2]. Studies in the literature ascribed the downward production trend to the competitive advantages of the competing countries with lower labor costs and favorable policies [3,4] as well as changing consumer preferences towards vine ripe tomatoes [5]. Across all producing states, Florida and California grow the majority of fresh tomatoes in the United States [3,6]. Imports, mainly from Mexico and Canada, surpassed domestic supply in the early 2010s, becoming the primary source of fresh tomato supply in the U.S. market. While there is a slow increase in Canadian imports of fresh tomatoes, imports from Mexico have grown rapidly and accounted for over 90% of the total U.S. import volume in the recent years (Figure 1). Mexico's domestic tomato production grew from 2.45 million metric tons in 2011 to 4.14 million metric tons in 2020 [7], with exports mainly destined to the United States [8]. The value of imported tomatoes from Mexico reached \$2.39 billion USD in 2021, by far the largest among all vegetables imported from Mexico [2]. Canada produced 0.26 million metric tons of fresh market tomatoes in 2020, with 60% exported to the United States [9]. In addition to foreign competition, the industry is facing several other challenges including labor shortages and rising production costs [10]. For example, Florida has set a goal for the minimum wage to reach \$15 USD per hour by 2026 from \$8.56 USD in 2020 [11]. Florida, the largest supplier of fresh tomatoes in the United States, has suffered significant losses caused by these issues.

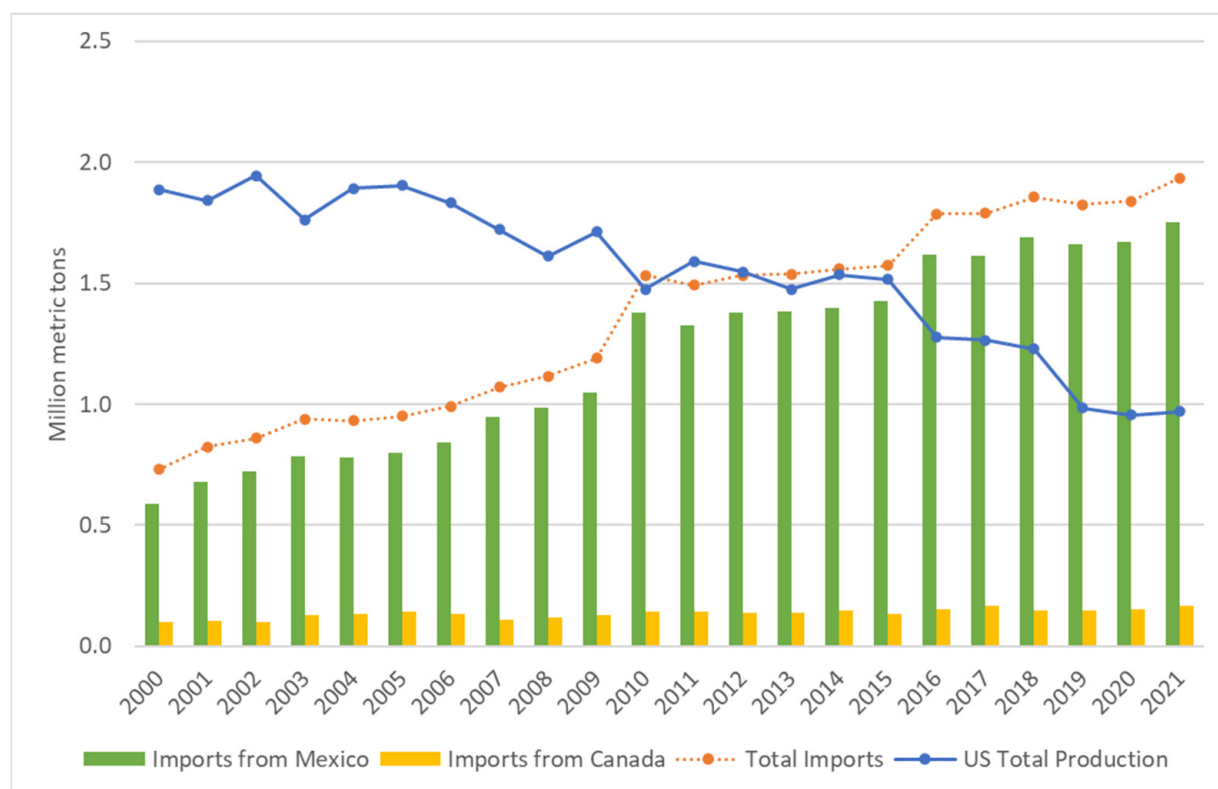


Figure 1. Fresh Tomato Volume (million metric tons): Imports vs. Domestic Production from 2000 to 2021. Source: USDA-ERS [2]; USDA-FAS [12].

Despite the importance of the crop and discussions on the trade and labor challenges, the industry is not well understood from the supply chain perspective. Understanding the supply chain structure and product flow from production to retail is essential to better inform business decisions and policy making. As such, this paper aims to provide a detailed analysis of the U.S. fresh tomato supply chain.

Because of production challenges, perishability, food safety, and cold storage requirements, the supply chain of fresh produce is complex and challenging to study. Few studies have evaluated the sustainability of tomato supply chains and tried to identify strategies to improve the overall supply chain resilience [1,13,14]. Gereffi et al. (2009) emphasized on the dietary health implications of the U.S. tomato industry. Chanda et al. (2021) explored the external drivers such as the social and environmental factors on the Florida tomato supply chain. Anastasiadis, Apostolidou, and Michailidis (2020) analyzed the Greek tomato supply chain from production, packaging, storage, and transportation to retail using a mapping approach.

In this study, we use the supply chain mapping approach. It is the first paper to depict the U.S. fresh tomato supply chain, describing the full details of different production practices, intermediary linkages, and marketing channels. Any impactful research and policy suggestions should be based on a deep understanding of the industry. Through supply chain mapping and discussions of the roles of and interactions among stakeholders, we aim to provide readers with valuable insights into the fresh produce industry. While trying to provide a big picture at the national level, we focus on the case of Florida fresh tomatoes for the illustration of the supply chain.

The remainder of the paper is organized as follows. The next section presents the methodology, and the third section provides the results with a detailed description and analysis of the supply chain structure. The final sections conclude the paper with a discussion and conclusions.

2. Methods

2.1. Supply Chain Modeling Theoretical Foundations

Three main methods have been applied in previous studies to model the complex network: (1) Life cycle assessment (LCA), (2) Quality controlled logistics (QCL), and (3) Supply chain mapping. Life cycle assessment (LCA) modeling has been utilized for evaluating the environmental impact and food waste along the produce supply chain [15–19]. These studies focus on specific practices at the production, processing, transportation, retail, and consumer level to discover the cumulative environmental footprint and food waste. Quality controlled logistics (QCL) modeling focuses on product quality. The method was applied to the Western-European tomato supply chain to optimize tomato supply with targeted quality at each step of the supply chain [20].

Supply chain mapping is a widely adopted methodology for presenting supply chain systems that involve multiple components [21]. Given the differences among industries and information to be emphasized, a supply chain mapping framework may be given different names. For instance, Supply Chain Operation Reference Model [22], Physical Structure Mapping, Process Activity Mapping, and more [23]. There is not yet a universal convention and term for these supply chain mapping methodologies [24]. Nonetheless, mapping a supply chain, introducing each supply chain component, and discussing the potential bottlenecks and other issues facing the supply chain system, is a formal research approach that researchers have broadly utilized. Researchers have utilized supply chain mapping frequently to evaluate the sustainability of supply chains and identify strategies to improve the overall supply chain resilience [1,13,14]. Tummala and Schoenherr (2011) used the supply chain mapping method to conduct a structured risk management process framework to assess general supply chain risks [25]. Tagarakis et al. (2021) mapped the data flow along the fresh produce supply chain to demonstrate how an open-access traceability system could improve the traceability and logistics of fresh produce [26]. Madevu, Louw, and Kirsten (2007) mapped the food sector's value flows and competitions among South African retailers [27]. Norwood and Peel (2021) used supply chain mapping to identify food supply chain vulnerabilities and risks [28]. Anastasiadis, Apostolidou, and Michailidis (2020) mapped the tomato supply chain in Greece and pointed out the hidden bottlenecks of the industry [1]. Supply chain mapping can also be used to identify critical environmental issues along the supply chain and to structure the research frameworks for environmental studies [29].

2.2. Supply Chain Research Questions

A supply chain is a network connecting the participants (individuals, departments, companies, etc.) involved in producing and delivering a product to consumers. Some may call it a “value chain” and interchange the two terms [21]. To be consistent, we will use the term “supply chain” throughout the article. Along a supply chain, the product's value is usually added from one stage to the next. Identifying the added value of specific products, such as the fresh market tomatoes, may be difficult. Some may argue that the tomato consumers purchase from grocery stores are still the same ones that pickers harvest from the tomato fields. However, to some degree, transporting, sorting, maturing, and packaging the tomatoes add value to them. For this reason, it is still appropriate to consider the farm-to-table process of fresh tomatoes as a supply chain system, allowing us to introduce it better using the supply chain mapping method.

Using the supply chain mapping method, we aim to help the readers to understand (1) how freshly harvested tomatoes end up on consumers' plates, (2) what are the major components along the fresh tomato supply chain and the dynamics among these players, and (3) what are the fresh tomato market mechanisms. This information will set the stage for us to discuss the challenges each major player in the U.S. fresh tomato supply chain is facing and the future research directions that can help to improve the supply chain resilience.

3. Supply Chain Structure of Fresh Market Tomatoes

Understanding the fresh produce supply chain suggests a dynamic mapping of stakeholders at every stage. First, an end-to-end mapping of product and information flow among stakeholders is depicted, including the detailed descriptions of major stakeholders' roles and interactions in the supply chain. Second, while demand is usually stable, the volatility of market price is mainly driven by changes in supply. The monthly prices of fresh tomatoes along the supply chain are presented to illustrate the seasonal market dynamics.

3.1. Supply Chain Mapping

From farm to fork, the fresh produce supply chain is formed by local growers and regional and global intermediaries, including growers-shippers, repackers, distributors, and retail outlets. Grower-shippers are growers that engage in production, packing, shipping, and selling. A repacker is a wholesaler that operates in ripening, resorting, and repacking mature green tomatoes into uniformity according to the timing and needs of customers, particularly the foodservice buyers such as the fast-food chains. Foodservice buyers and retailers often contract with distributors to manage the shipping logistics. The use of distributors by retailers has seen a decreasing trend, with more retailers directly purchasing from grower-shippers [5]. This section provides detailed descriptions of the roles and interactions among tomato industry participants along the supply chain.

The end-to-end map shows the product flow from production to retail and information feedback from retail back to production. The supply chain network is continuously adapting in response to product availability, changing consumer spending patterns and preferences. Over time, it has developed into two main branches, supplying tomatoes harvested at different maturity levels (mature green and vine ripe tomatoes), thus forming a unique marketing process that is distinguishable from other produce [5]. In Figure 2, we depict that most fresh tomatoes are marketed either through retail or foodservice networks. The supply chain can be further divided into stages from farm to fork, with each stage involving different entities: (1) production, (2) intermediaries engaging in the activities of packing, repacking, wholesale, and distribution, and (3) retail, involving retailers and foodservice buyers (Figure 2).

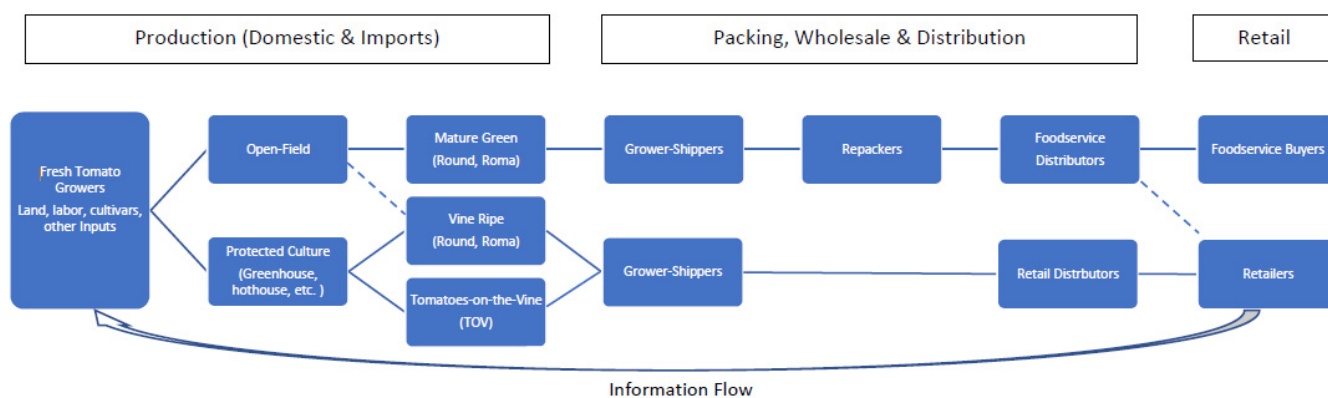


Figure 2. U.S. Fresh Market Tomato Supply Chain.

3.1.1. Growers

The number of fresh tomato farms in open-field production has declined 13% from 31,047 in 2012 to 27,122 in 2017 and concentrated into fewer but more extensive operations, with 15 farms accounting for a third of the national tomato acreage, within which eight are in Florida (Figure 3).

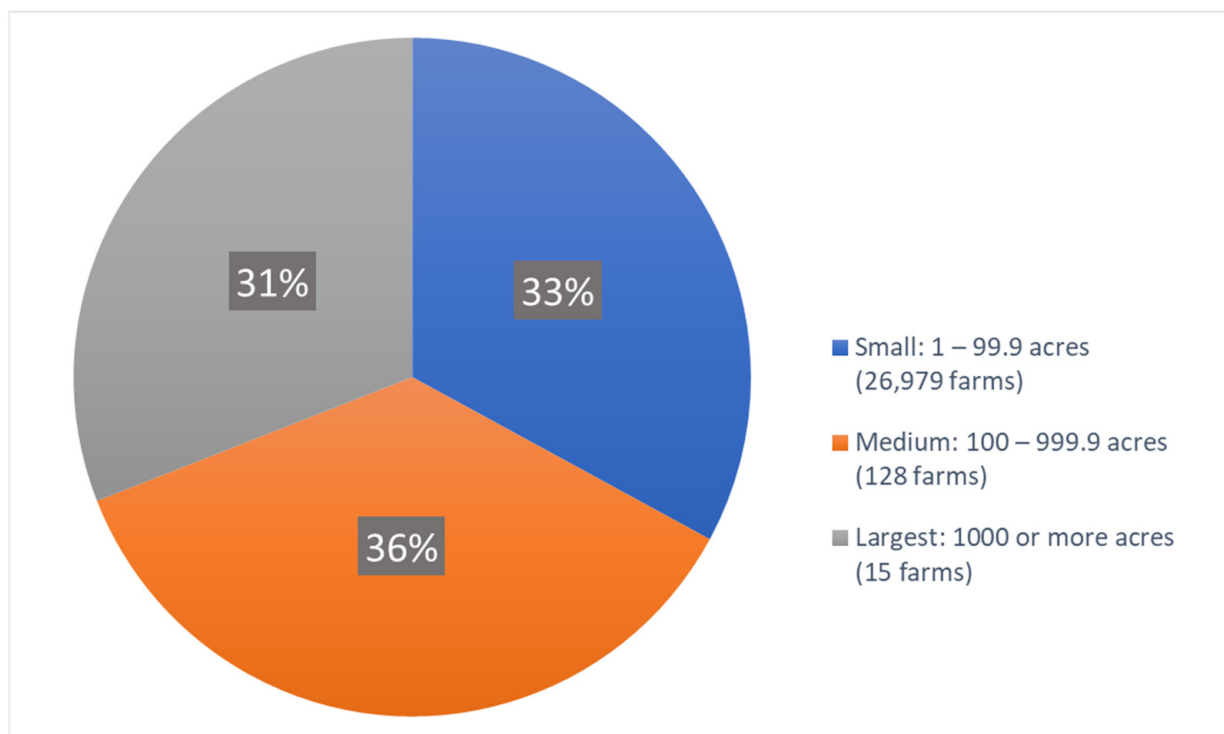


Figure 3. Structure of U.S. Open-field Fresh Tomato Production (Percentage of Farms by Size). Source: USDA-NASS [30].

Small to medium size growers operate tomato farms anywhere between a few acres to a few hundred acres (one acre equals 0.405 hectares) and market in the direct-to-consumers sector, including farmers' markets and roadside stands. They often grow other vegetables and produce other horticulture products, offering various products for direct sales to consumers. In contrast, large-size growers or grower-shippers have integrated operations and are in the business of growing, packing, transporting, and selling nationwide, mainly through distributors.

Production Systems

Tomatoes can be grown in open fields or protected structures such as high tunnels and greenhouses. In the United States, the majority of tomatoes are grown in the open fields. While Florida's open-field production was valued at \$324 million USD in 2021, ranking number one, California surpassed Florida in open-field fresh tomato production volume in 2020 (Figure 4). From 2000 to 2015, the average yield of Florida fresh tomatoes dropped from 44,834 kgs to 32,267 kgs per hectare, a 26.3% reduction [31]. Such yield loss is primarily caused by the prohibition of methyl bromide fumigation in the open-field production [3,32,33]. The industry estimated the prohibition caused up to 20% yield loss [32]. Methyl bromide was a powerful soil fumigant used to control soilborne pests and diseases, which was jointly agreed by U.S., Canada and other developed countries to phase out its use by 2005 and developing countries including Mexico by 2015 under the Montreal Protocol because of its ozone-depleting effects [34]. Another reason for the yield reduction is the depressed market prices due to growing import competition and rising harvesting and marketing costs. When market prices are lower than the harvesting and marketing costs, especially in late seasons, growers would stop harvesting and abandon the crop, which would reduce the harvested yield sent to the market.

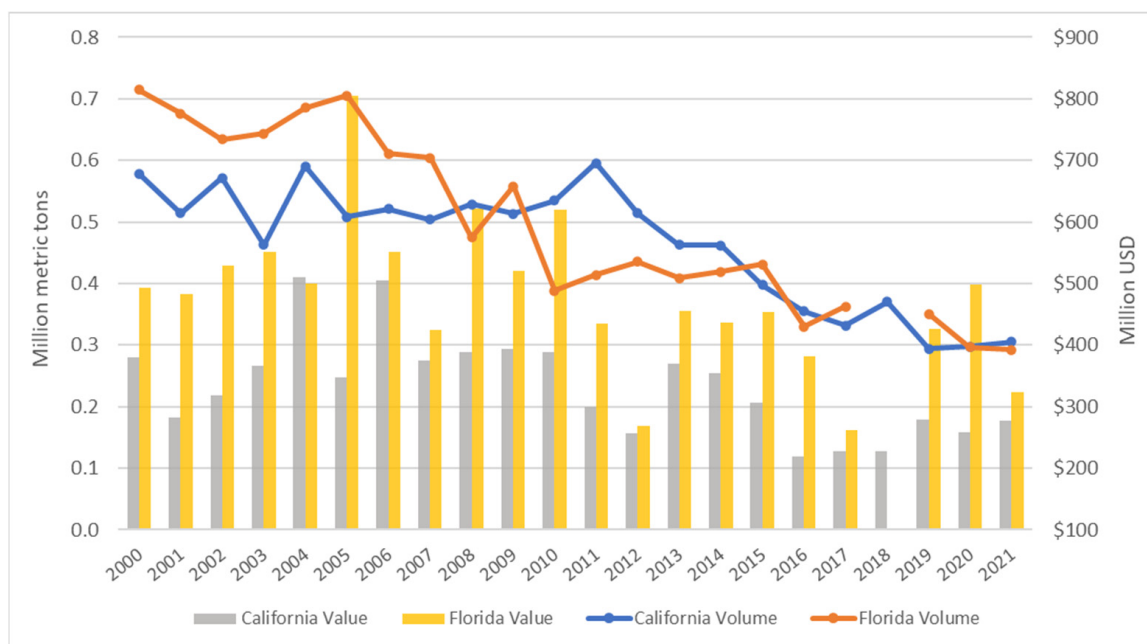


Figure 4. Volume (million metric tons) and Value (million USD) of Open-field Fresh Tomato Production: California and Florida from 2000 to 2021. Note: FL value and volume in 2018 are undisclosed from the data source. Source: USDA-NASS [31].

Use of protected culture has grown in recent years, with tomatoes produced in high tunnels and greenhouses gaining market shares. The total domestic production of tomatoes under protection has tripled over five years (2014–2019), increasing from 36,095 metric tons in 2014 to 131,685 metric tons in 2019, representing nearly 13.4% of total U.S. fresh tomato production in 2019 [31]. Given the higher costs associated with the protection structures, production under protection is usually intended for sale directly to the fresh market. As the adoption of this technology expands over time, the landscape is constantly changing, with the top-producing states of tomatoes under protection being Tennessee, California, Texas, Utah, Kentucky, and Colorado in 2019 (Table 1).

Table 1. Tomatoes under Protection Production, Top Producing States by Volume (metric tons), 2014 and 2019. Source: USDA-NASS [31].

State	2014	2019
California	8299	20,691
Colorado	-	7820
Kentucky	319	8073
Tennessee	-	23,202
Texas	-	19,927
Utah	53	8793
Other States	27,425	43,180
U.S. Total	36,095	131,685

Open-field production is the primary production method adopted by Florida growers [14]. The warm weather in Florida is the main reason for the low adoption of protected production. Greenhouse production has many advantages over open-field production, such as complete control of the growing environment and year-round production [35]. Nearly 67% of Mexico’s tomato production uses protected agriculture systems, and almost 84% of these are exported, with the United States being the primary destination [8]. In Canada, greenhouse tomatoes completely dominate the fresh tomato market, with 60% exported to the United States [9].

Varieties

The main varieties of tomatoes include round, roma/plum, grape, cherry, and other specialty varieties. Before laying down the plastic mulch, growers inject the beds with fumigants to manage pest and disease pressure [36]. Tomato seedlings are transplanted later, typically spaced 46 to 61 cm apart. Stakes are driven into the beds between plants to support the fruits. Planting takes place at intervals throughout the season to ensure continuous supply throughout the season. Tomatoes mature 90 to 110 days after transplanting and are harvested by hand [36]. Most Florida-grown tomatoes are harvested at the mature green stage, which the foodservice sector prefers for better slicing characteristics, while vine ripe tomatoes are harvested at the ripening stage. During the harvest season, growers pick two or more times at 7- to 10-day intervals [36]. Round tomatoes are hand-picked into 14.51 kg (32-pound) buckets and are then transported to the packinghouse.

Tomatoes-on-the-vine (TOV), which are increasingly popular in the market, are primarily grown in protected structures and packaged directly after harvest. Roma tomatoes, traditionally used for canning and cooking, can be produced in the open fields and under protected systems and have gained market shares in retail outlets (Table 2). Snacking varieties such as grape, cherry, and other specialty varieties have also gained popularity [37]. Market prevalence of these specialty varieties has increased in retail and foodservice sectors, with more growth potential from the snacking varieties [37]. Driven by the increase in consumers’ awareness of health and wellness and willingness to try tomatoes with varying attributes, some growers are expanding their offerings to include these specialty tomatoes.

Table 2. Fresh Tomato Varieties. Source: Cook, 2015 [37].

Tomato Varieties	Mature Stage	Production System & Characteristics
Round tomatoes	Mature green	Harvested from the open fields at stage 2 before changing color, then treated to induce ripening. Preferred by the foodservice sector for firmness and slicing characteristics.
	Vine ripe	Harvested from the open fields at ripening stages. The main variety sold at retail.
	Tomatoes-on-the-vine (TOV)	TOVs are produced under protection and preferred by consumers.
Roma/Plum	Mature Green/Vine ripe	Roma tomatoes can be produced in open fields and protected structures. These are traditionally used for canning or cooking.
Grape, cherry & other specialty tomatoes	N/A	These tomatoes can be produced in open fields and protected structure. Snacking varieties have gained popularity in all segments.

Grading and Sizing

Field-grown tomatoes are graded as U.S. No. 1, Combination (consists of U.S. No. 1 and 2), No. 2, and No. 3, whereas there are only two grades for the hothouse tomatoes, U.S. No. 1 and No. 2. U.S. Combination requires at least 60% to be U.S. No. 1 grade tomatoes. Grading is based mainly on external appearances, bruising, and firmness [38].

The sizing of round tomatoes is based on U.S. grade standard size designations (small, medium, large, extra-large) or a Florida Marketing Order (FMO) size [38]. They are numerically identified on the tomato cartons, 5 × 6, 6 × 6, or 6 × 7. Each indicates the number of rows by the number of columns each carton holds.

Seasonality

Field-grown tomatoes are supplied mainly from May to November in California and from October to June in Florida [35]. Other states supply the market during the summer. Most field-grown tomatoes from Mexico are produced in Sinaloa from December to April,

which overlaps the Florida season, making Mexican imports the direct competitor of Florida tomatoes [8,35]. For greenhouse tomatoes, both United States and Mexico have year-round production while Canada supplies the market for ten months from March to December (Table 3).

Table 3. North America Open Field and Greenhouse Tomato Availability by Region. Source: Cook and Calvin, 2005 [35].

	January	February	March	April	May	June	July	August	September	October	November	December
Open Field	CA				✓	✓	✓	✓	✓	✓	✓	
	FL	✓	✓	✓	✓	✓				✓	✓	✓
	Rest of U.S.						✓	✓	✓			
	Sinaloa, MX	✓	✓	✓	✓							✓
Greenhouse	U.S.	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	Canada			✓	✓	✓	✓	✓	✓	✓	✓	✓
	Mexico	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

In 2020, Florida produced approximately 0.34 million metric tons of fresh market tomatoes from 10,117 hectares of land [31]. Figure 5 presents the percentage of the total acres for all vegetables in each Florida county that was used to grow tomatoes in 2017, representing the tomato industry concentration at the county level. Tomato production is concentrated in the central and southern regions of Florida. In the central region, harvesting peaks in November and December and then April to June. Southern production has one continuous season from October to April, peaking in January through March.

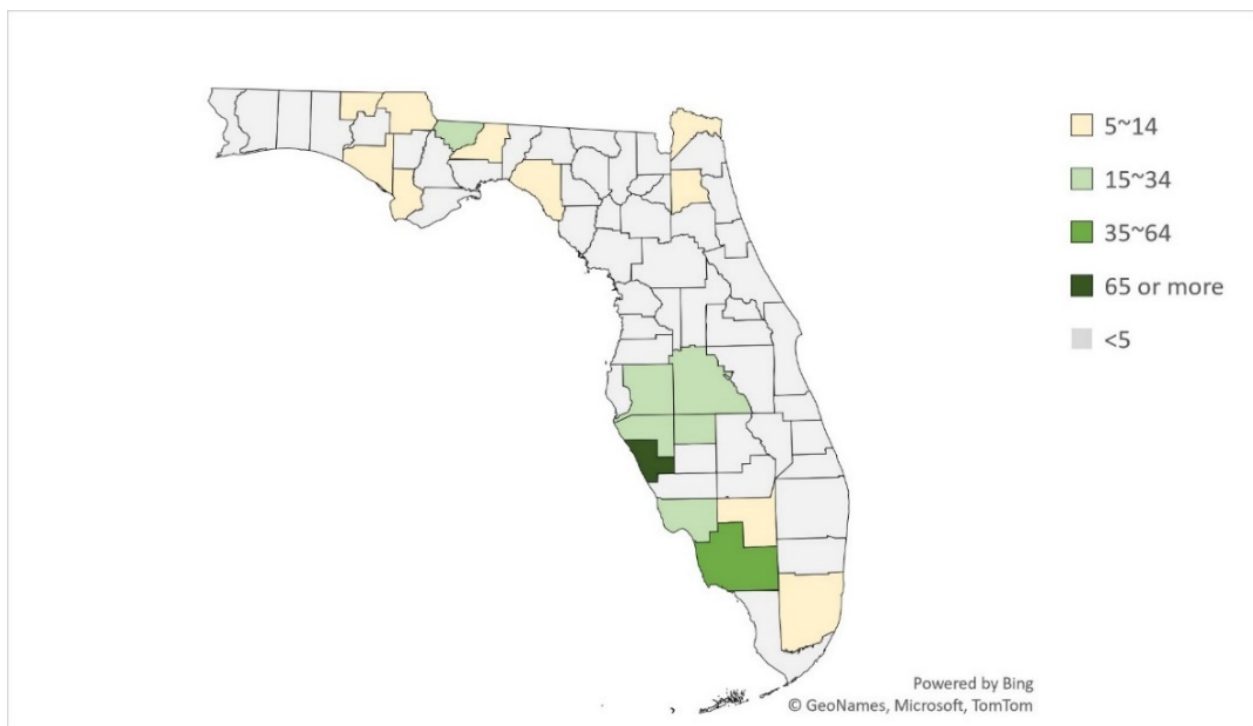


Figure 5. Florida Tomato Production Map: Concentration (%) of Hectares Harvested for Sale. Source: USDA-NASS [30].

3.1.2. Grower-Shippers

In addition to decreasing producer numbers, the number of grower-shippers has decreased due to various challenges, such as foreign competitions [4,6,39], competing uses of domestic land, relatively low profitability, and ongoing labor shortages [40,41]. Volume shipped remains concentrated among handlers. In 2021, there are 41 registered handlers in Florida compared to 65 in 2000 (37% reduction) [42]. These registered tomato handlers include grower-shippers, repackers, distributors, and other wholesalers.

Due to the pandemic disruption, the volume of Florida tomato shipments hit a historic low in 2021 at 0.28 million metric tons [43]. The shipment has continued decreasing for the past two decades (Figure 6).

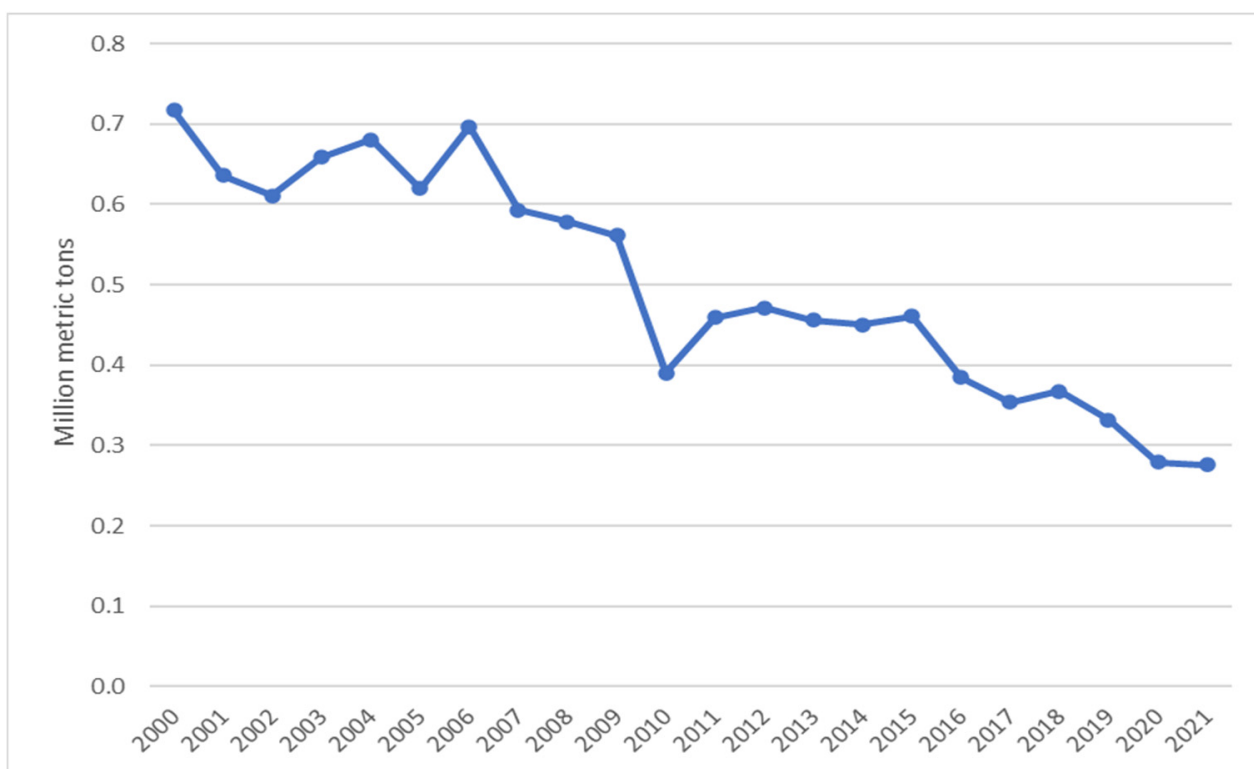


Figure 6. Florida Tomato Shipping Volume (million metric tons) from 2000 to 2021. Source: USDA-AMS [43].

Grower-shippers typically have several growing locations across Florida and other states to ensure a continuous supply as demanded by buyers. After each harvest, tomatoes are transported to the packing facility to be cleaned, sorted, graded, and packed by size and color. The Florida Tomato Committee regulates the handling of tomatoes to ensure practice and quality standards [42]. Standard tomato quality is primarily based on uniformity of shape, color, and degree of injuries [44]. Mature green tomatoes are packed into a standard carton of a net weight of 11.34 kg (25 pounds). Ten of these cartons are then stacked onto one pallet. Pallets are then handled by forklift trucks [45]. Grower-shippers then ship the packed tomatoes to re-packers or sell directly to wholesale markets such as terminal markets and foodservice businesses across the country. Grower-shipper often engages in export, with Canada being the leading export destination of Florida tomatoes [42]. Shipment of mature green tomatoes accounts for 85% of the total volume of round tomatoes, with vine-ripe shipments accounting for the rest of the volume (Table 4). Shipment of U.S. No.1 accounts for 66% of the total volume of round tomatoes [42].

Table 4. Florida Shipment of Round Tomatoes (Percentage of Volume by Color, Grade, and Size). Source: Florida Tomato Committee [42].

Season	Maturity		Grade			Size		
	Green	Ripe	85% U.S. #1	U.S. Combo	U.S. #2	5 × 6	6 × 6	6 × 7
2020/2021	85%	15%	66%	16%	18%	50%	33%	17%
2019/2020	85%	15%	65%	15%	20%	50%	32%	18%
2018/2019	88%	12%	63%	19%	18%	49%	33%	18%
2017/2018	87%	13%	59%	24%	17%	51%	32%	17%
2016/2017	87%	13%	52%	33%	15%	52%	33%	15%

3.1.3. Repackers

Repackers are the unique agents in the supply chain of mature green tomatoes. They are often wholesalers who buy from growers or grower-shippers, ripen and repack tomatoes into uniformity based on different buyers’ needs, and sell directly to the buyers. Before shipping, mature green tomatoes are typically held in the ripening chambers and exposed to ethylene gas to induce uniform ripening [36]. The green tomatoes can be stored in the maturing room for somewhere from 5 to 7 days, depending on the size of the tomato. Once tomatoes reach light pink color, repackers resort and repack the tomatoes in different sizes and colors based on specific orders. For example, wholesalers at terminal markets prefer tomatoes at a ripening stage of 5 with light red color (Figure 7) as they sell to restaurants requiring the ability to use the product immediately. In contrast, grocery stores and fast-food companies may prefer tomatoes with a light pink color (Figure 7).













Stage	(1) Green	(2) Breakers	(3) Turning	(4) Pink	(5) Light red	(6) Red
Picture (Round)						
Picture (Roma)						
Surface color	100% green	<10% yellow/pink	10~30% yellow/pink	31~60% pink/red	61~90% pinkish-red/red	>90% red

Figure 7. Tomato Color Classification. Source: USDA-AMS [38] and photos taken by the authors.

3.1.4. Distributors

Distributors are vital players in the supply chain. They are often wholesalers who buy, store, sell, and transport to buyers. The food distribution industry is segmented into two main sectors providing service to retailers and the foodservice outlets. The retail distributors sell to retailers such as supermarkets, convenience stores, and other food stores. The foodservice distributors serve restaurants, hospitals, hotels, and other institutions [5]. Retail distribution accounts for 41% of the wholesale grocery volume, whereas foodservice wholesale accounted for 23% of the total volume in 2012 (the most recent year in which data is available) (Figure 8).

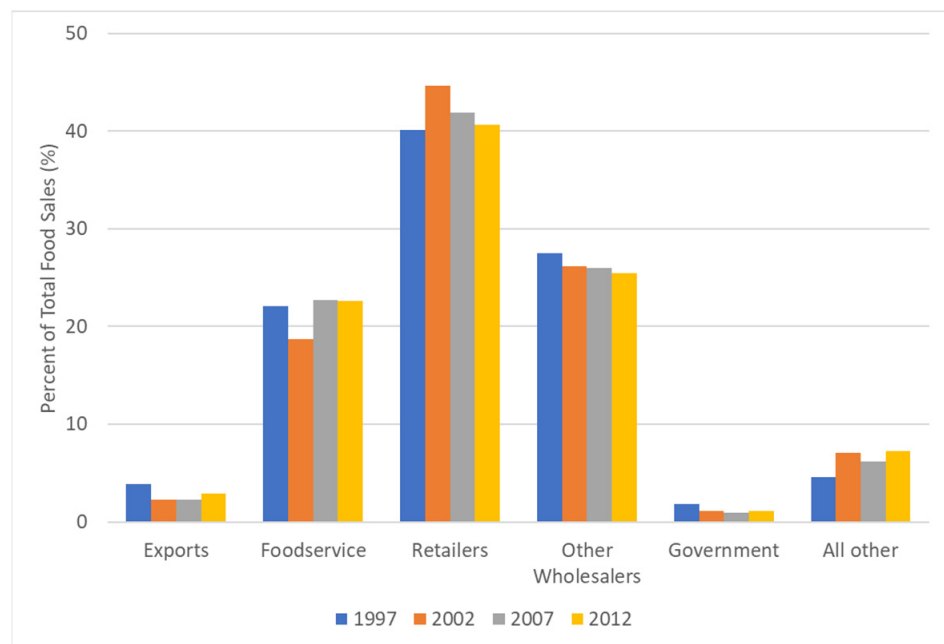


Figure 8. Percentage of Total Food Sales by Type of Outlet. Source: USDA-ERS [46].

The food distribution sector is concentrated, with a few large companies continuing to expand their scale and reach. C&S Wholesale Grocers lead the retail distribution. Sysco and U.S. Foods lead the foodservice distribution [46]. Due to the disruption from COVID-19, foodservice distributors experienced significant losses due to restaurant and institution closures, while retail distributors gained considerable market share. Capstone reported that during the pandemic, many foodservice distributors shifted and expanded their profile into the retail space, particularly in the specialty food categories, which expects to be the main driver for future mergers and acquisitions [47].

Truck driver shortages remain the biggest challenge in distribution and transportation. USDA-AMS tracks the availability of refrigerated trucks by shipping point on a scale of 1 to 5, with 1 representing surplus and 5 representing a shortage (Figure 9a). In early 2022, Florida experienced the highest level of truck shortages compared to California and Mexico crossing through Arizona and Texas [48]. Truck rates have been increasing sharply across all states since 2020, with California truck rates nearly doubled (Figure 9b). Companies have invested heavily in technological innovations to enhance logistic efficiency [47].



Figure 9. (a) U.S. Average Refrigerated Truck Shortage by Origin from 2000 to 2022; (b) U.S. Average Refrigerated Truck Rates (USD per km) by Origin from 2000 to 2022. Source: USDA-AMS [48].

3.1.5. Retailers and Foodservices

Due to the COVID-19 pandemic, which motivated an unprecedented increase in at-home cooking, the consumption of vegetables has seen significant growth, with households spending 15% more on grocery store fresh tomatoes in the first quarter of 2020 compared to the previous two years [49]. The COVID-19 pandemic strengthened the market power of retailers who gained larger shares of consumers' spending on food from early 2020 to early 2021 as food-away-from-home options experienced a sharp decline in sales due to restrictions and business closures caused by the pandemic.

There appears to be a recovery in the foodservice industry, with the market share of food-away-from-home sales gradually recovering to the pre-pandemic level (Figure 10). The recovery of the food service industry may stimulate the demand for U.S. domestic mature green tomatoes. However, if consumer behavior continues to favor eating more at home post-pandemic, this may further drive the retail market growth. The foodservice sector has provided a stable demand for mature green tomatoes. Field-grown mature green tomatoes are preferred by the foodservice sector for their firmness and slicing characteristics. The top buyers for mature green tomatoes include fast food giants McDonald's, Subway, and Yum Brands, among others.

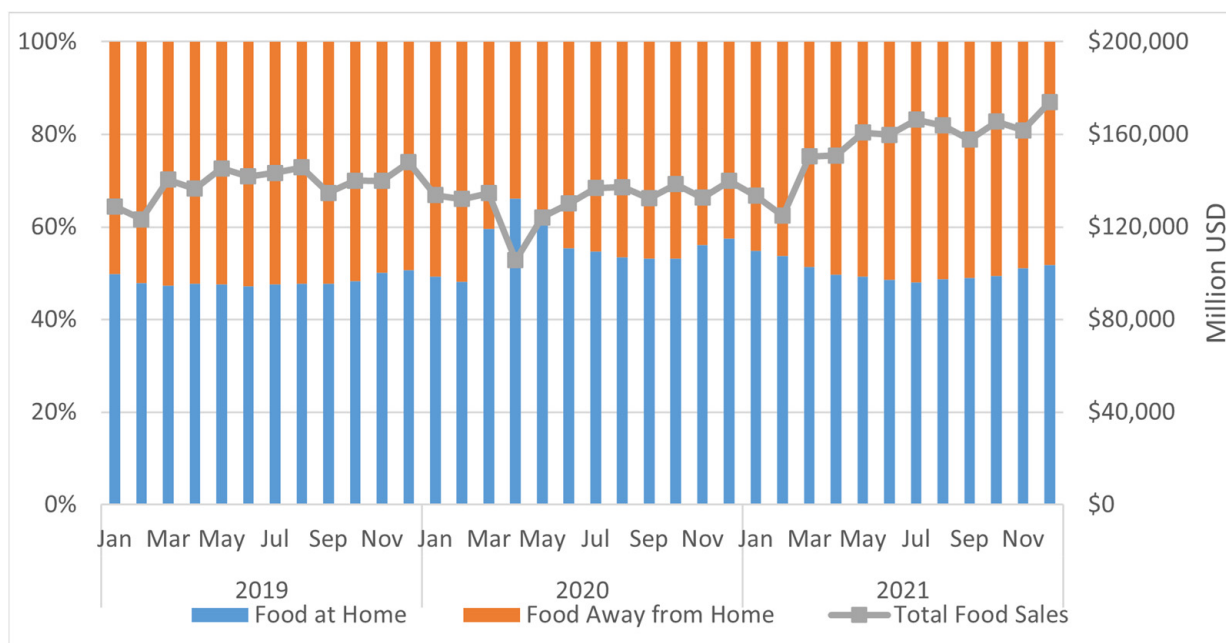


Figure 10. U.S. Consumer Total Food Expenditure by Type from 2019 to 2021. Source: USDA-ERS [50].

Consolidation has occurred at all levels of the supply chain, particularly the retail level. The number of retailers has decreased over the years, with the four largest retailers accounting for nearly one-third of U.S. food sales. These top four largest retailers are Walmart, Kroger, Albertson's, and Target [46]. To deal with the greater volume and continuous supply needs from retailers, it requires distributors and grower-shippers to have the capacity to source globally or produce year-round. Therefore, greater market shares will be captured by larger suppliers, whereas smaller growers or grower-shippers may find it difficult to fulfil these large retailers' buying needs [5]. The consolidation in the U.S. food retail market further drives the consolidation of the entire produce supply chain with large players controlling the main food supply.

In 2020, grocery stores, including supermarkets (except convenience stores), account for the largest market share, with 93.0%, followed by convenience stores without gasoline (3.9%) and specialized food stores (3.1%) (Figure 11). Notably, supermarkets and other

grocery stores increased by 10.1% (\$66,948 million USD) in sales in 2020 from the previous year, leading to grocery sales growth during the pandemic [51].

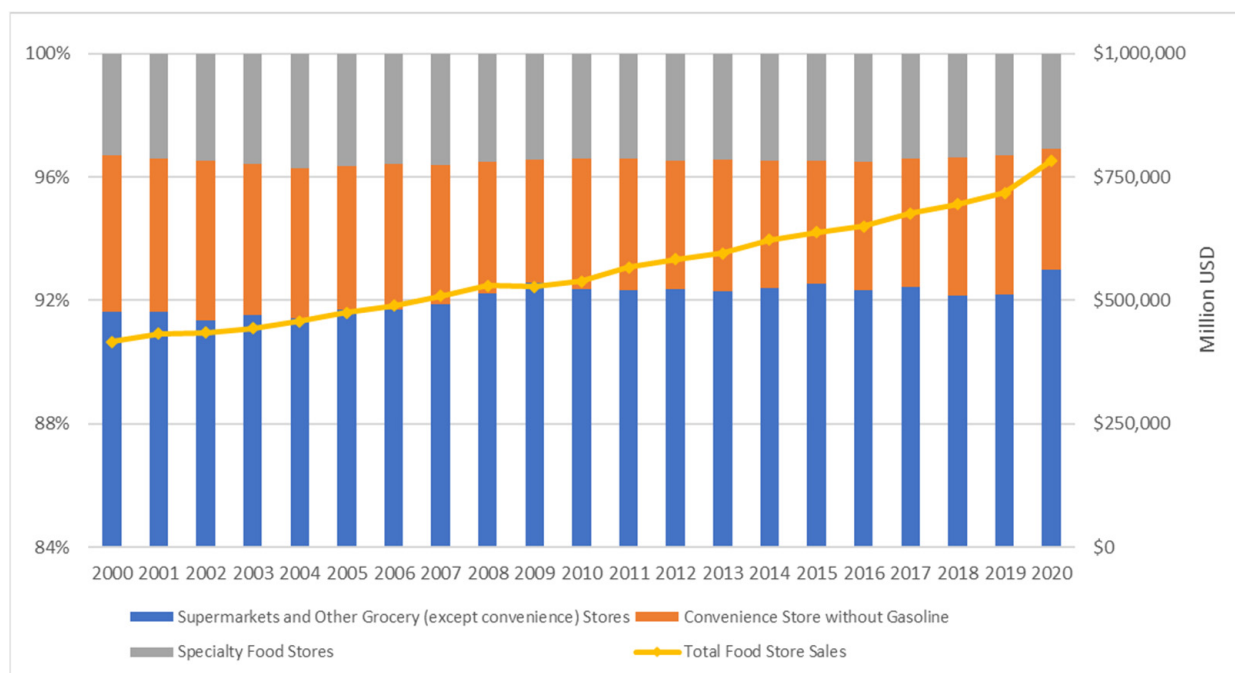


Figure 11. U.S. Grocery Market Share by Segment and Food Stores Sales in Million USD from 2000 to 2020. Source: U.S. Census Bureau [51].

3.2. Price Trends along the Supply Chain

Market prices of fresh tomatoes fluctuate based on supply and demand. While demand is usually stable, the volatility is mainly driven by changes in supply conditions, primarily determined by weather events and growing conditions over the season [52]. This section describes the seasonal price trends of major varieties of round tomatoes at the shipping point, terminal market, and retail level, including a comparison of domestic supply and imports, using the data from USDA Agricultural Marketing Services.

3.2.1. Shipping Point Price Trend

The 10-year monthly average prices show that the prices of mature green tomatoes are, on average, 15% higher (9% lower) than the prices of vine ripe tomatoes for the first (second) half of the year (Figure 12a). The price difference between the two varieties peaks in December when vine ripe tomatoes are about 42% more expensive than the mature green ones (Figure 12a). This seasonal trend also reveals the relationship between the prices of Florida tomatoes and Mexican imports. Imported vine ripe tomatoes are priced lower than domestic mature green tomatoes from February to June but higher than domestic mature green tomatoes, particularly in November and December. The prices of mature green tomatoes primarily represent those of Florida, as most of the recorded volume of mature green tomato shipments are from Florida. The vine ripe prices act as a proxy for Mexican import prices as nearly all (greater than 90%) are shipped from Mexico [43].

The shipping point price differences between the mature green and vine ripe tomatoes can also be partially explained by the difference in costs of production. Costs of fresh tomato production include labor wages, irrigation, chemicals, and other input costs. Harvesting tomatoes is labor-intensive, accounting for more than 30% of the total costs in mature green tomato production [36,53]. The unit cost of Florida mature green tomatoes is estimated at \$0.87 USD per kg [36]. Vine ripe tomatoes require more pickings resulting in higher labor costs per unit. However, production costs of vine ripe tomatoes paid by Mexican producers are much lower due to lower input costs [3].

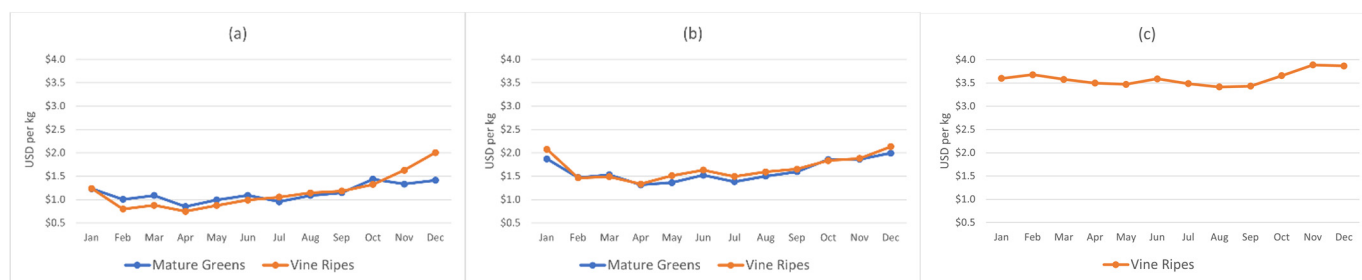


Figure 12. (a) Monthly Average Shipping Point Prices of Mature Green and Vine Ripe Tomatoes (USD per kg) from 2012 to 2021; (b) Monthly Average Terminal Market Prices of Mature Green and Vine Ripe Tomatoes (USD per kg) from 2012 to 2021; (c) Monthly Average Retail Prices of Vine Ripe Tomatoes (USD per kg) from 2012 to 2021. Source: USDA-AMS [43].

3.2.2. Terminal Market Price Trend

Forward contracting is a market risk management technique buyers and producers employ to mitigate price volatility exposure [5]. The USDA-AMS reported terminal market prices, which are good references for wholesale prices, yet these prices only represent the daily spot markets, and contracting prices are not included [5]. Nonetheless, the prices recorded can still reveal the seasonal trend and pattern that are useful in understanding the pricing along the supply chain.

Compared to the shipping point prices, a review of the 10-year monthly averages revealed that terminal market (wholesale) prices of mature green and vine ripe tomatoes tend to follow a similar seasonal trend but with a much closer movement (Figure 12b). During many months of the year, vine ripe tomatoes (mainly imports from Mexico) are priced nearly the same as mature green tomatoes (mostly from Florida). The price movements are much more synchronized than those at the shipping point. The differences between shipping point and terminal market prices reflect the markups at the wholesale level. These markups include costs occurring at the wholesale level, such as transportation costs. Wholesale markups of vine ripe tomatoes show higher variability than those of mature green ones.

3.2.3. Retail Price Trend

Vine ripe round tomatoes are the main variety marketed at retail stores, whereas mature green tomatoes are sold to the foodservice buyers. Only the retail prices of vine ripe tomatoes are available through USDA-AMS. Compared to the shipping point and the terminal market prices, the retail price movement shows a much flatter trend indicating the price volatility at the retail level is much less than that of the terminal and farm levels (Figure 12c). A potential explanation for a less volatile price trend at the retail level is that the retail stores may intentionally flatten the curve to sustain sales to retail consumers, who can be very sensitive to prices. Furthermore, a high markup from wholesale to retail, averaging \$2 USD per kg of fresh tomatoes [43], allows the retailers to stabilize the price curve at the retail level. These monthly retail prices represent those of non-organic tomatoes. Organic vine ripe tomatoes are priced higher, with an average premium of \$1.98 USD per kg [43].

4. Discussion

4.1. Seasonality

The seasonality element of fresh produce supply chain is unique compared with other industries, which is a significant factor in shaping the movement of fresh tomatoes along the supply chain. Fresh tomatoes from Florida are entering the market from October to June, and the rest of the U.S. production is picking up in spring and peaking throughout summer [54]. The highest volume from Mexico enters the U.S. market from late fall through

winter, coinciding with supply from Florida. As such, Mexico has become Florida's main competitor in the fresh tomato market [5].

Production method determines the seasonal length and the varieties being grown. Open-field production is highly seasonal, primarily adopted by U.S. growers. Greenhouse production can supply year-round, which is fully adopted by Canada. Nearly 67% of Mexico's tomato production uses protected culture systems [8]. Varieties such as the popular tomatoes-on-the-vine (TOV) are primarily grown in protected structures.

Previous studies emphasized the value mapping of tomato supply chains without taking the seasonal factor into consideration [1,13–15]. While the current study provides a complete picture of the supply chain, future research should consider a spatial representation of the fresh produce supply chain by factoring in seasonality.

4.2. Perishability and Shelf Life

The heterogeneous nature of product quality complicates the optimal management of the fresh produce supply chain. Product quality management, such as maturity level, appearance, taste, and shelf life, plays a vital role in designing an efficient supply chain [20]. For example, different markets require tomatoes harvested at different maturity levels (mature green and vine ripe tomatoes). Repackers can accommodate such individual needs better by ripening mature green tomatoes to target stages, resorting and repacking in different sizes and colors.

Perishable food generally has a short shelf life, and the length is primarily determined by handling environmental conditions such as temperature and humidity [55]. It typically takes tomatoes 4 to 10 days from harvest to reach the shelf [20]. After reaching retail stores, fresh tomatoes may have a remaining shelf life of up to a week [55]. Vine ripe and other greenhouse varieties take less time to reach retailers, whereas mature green tomatoes spend additional days in the maturing room (5 to 7 days), resulting in a longer time to reach the shelf. A longer supply chain may suffer a higher risk of quality degradation, resulting in less ideal appearance, taste, and shelf life [20]. Researchers should consider modeling quality distributions at different stages when designing a framework for optimizing fresh produce supply chain.

4.3. Transportation

Transportation plays a vital role in the fresh produce supply chain, substantially impacting distribution efficiency and product quality. Truck driver shortages remain the biggest challenge in transportation, with the American Transportation Research Institute identifying truck driver shortage as the number one issue in the transportation industry [56]. In addition, the cost of trucking has been increasing sharply across all states, with California experiencing the highest trucking costs. With the intensifying trucker shortage coupled with the rising cost of transportation, the industry's sustainability is at stake. Logistic solutions should be a priority for future research.

5. Conclusions

With the ongoing macroeconomic shocks exposing the vulnerability of global food supply chains, it is essential to understand the complexity of fresh produce production and supply. As one of America's most consumed vegetables, fresh tomatoes present an interesting and important case for produce supply chain studies. In this paper, we provided a complete picture of the U.S. fresh tomato supply chain. The end-to-end mapping depicts the flow of product and information along the fresh tomato supply chain and provides detailed descriptions of stakeholders' roles and interactions. The discussion of price trends revealed the industry's market dynamics, highlighting the importance of supply chain management with consideration of seasonality.

Several concerns emerged as we diagrammed the industry in the previous section. Providing year-round supply accompanied by a diversified portfolio of varieties seems crucial to gaining market shares. However, the U.S. growers' adoption of protected structures

is low because of climate limitations and the high capital investment requirement. The total greenhouse vegetable and fruit acreage were only 2853 acres (1155 hectares) across the United States in 2017 [6,30]. Open-field production is highly seasonal and can be easily disrupted by natural hazards such as weather events. In terms of varieties, the foodservice sector has provided a relatively stable demand for mature green tomatoes. Vine ripe tomatoes are growing in popularity among consumers over the years but remain a relatively small share of U.S. domestic production. This may change in the future if new vine ripe varieties better adapted to the climate or labor-saving varieties or harvesting technologies are developed to make production more profitable under growing foreign competition. From a logistic standpoint, the supply chain of mature green tomatoes is usually longer than that of vine ripe tomatoes, given the need for mature green tomatoes to be repacked. A longer supply chain often requires more handling and processing, which may result in higher transportation and storage costs, greater food waste, and products taking a longer time to reach shelves. In addition, farm worker and truck driver shortages continue to challenge the sustainability of the labor-intensive produce supply chain from production to distribution. For instance, domestic labor in Florida crop production decreased by nearly 25% from 2000 to 2020 [57], and the refrigerated truck shortage level in Florida reached 4.3 on a 1–5 scale in 2022 (Figure 9). Addressing these issues along the supply chain is key to sustaining the U.S. fresh tomato industry.

To summarize, this paper provides a comprehensive analysis of the fresh tomato supply chain and lays the groundwork to guide future research to resolve issues and challenges facing tomato supply chain participants. Improved understanding of the roles and interactions among supply chain participants is a crucial step to help policymakers and stakeholders make better-informed decisions to improve industry coordination and competitiveness, expand U.S. market demand, and build supply chain resilience. The supply chain mapping reveals opportunities for research on systemic solutions to industry sustainability issues previously overlooked but important for business decisions as well as policymaking.

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