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RESEARCH PAPER

Developing an Optimized Pricing Mechanism for Super Fresh Products Considering Product Shelf-Life

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Abstract

This study aims to develop a mathematical model for the pricing of fresh products in a fruit supply chain network. Stakeholders in this issue include fruit suppliers, primary fruit fields and markets, retailers, end customers, processing industries, and disposal centers. Fruits and vegetables are considered super fresh products because their color and taste change over time, leading to spoilage. This article focuses on pricing this category of products considering freshness-dependent demand and pricing and models the flow among suppliers, retailers, customers, processing industries, and disposals. This study examines the pricing of fresh products supplied by suppliers, transported, sold by retailers, and eventually delivered to customers and processing industries and disposals, and considers multiple periods. The developed model uses mixed integer linear programming (MILP) to maximize total profit, including transportation, wholesale, and inspection costs. A numerical example is provided to validate the proposed model and offer managerial insights to the relevant industry. The results indicate that appropriate pricing contributes to overall profit and increased sales. Lastly, sensitivity analysis demonstrates the relationship between total profit, freshness, and product sales. A total profit model for retailers is considered to optimize pricing based on optimal cost parameters.

Keywords:
Fresh Product Supply Chain, Pricing, Demand Management, Quality and Freshness, Waste Reduction.

Introduction

In today's challenging and competitive scenario, retailers are considered crucial links in the supply chain network with a direct connection to the end consumer (Ziari and Sajadieh). The supply chain, referring to all parts of production, distribution, and product and service delivery, encompasses activities and decisions that directly or indirectly impact final customer demand. Alongside product or service offerings to customers, price plays a significant role in determining the quantity of goods and/or services that consumers are willing and able to purchase (Ahumada and Villalobos 2009). An increase in the price of a product may lead to a decrease in consumer demand. Among the various supply chains existing worldwide, food

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supply chains play a vital role in ensuring human health and safety. Various necessities such as meat, vegetables, grains, fruits, dairy products, and others are recognized in societies, with fruits and vegetables playing a crucial role in providing nutritional benefits and contributing to healthy dietary habits for nations (Rekik and Sahin 2012). Their regular consumption is recommended by international communities focused on nutrition and health due to their richness in vitamins, minerals, dietary fiber, and polyphenols. Fresh vegetables are sources rich in vitamins, minerals, dietary fiber, and polyphenols, and their regular and daily consumption helps reduce the risk of chronic diseases such as diabetes, strokes, cardiovascular diseases, and atherosclerosis (Zhang, Liu et al. 2015).

Despite the significant nutritional resources found in fruits and vegetables, one of their most prominent challenges lies in their supply chain. The supply chain, which essentially encompasses all aspects including sourcing of products, transportation, storage and distribution, retailing, and the inventory and financial flow from the starting point to reaching the end customer, involves the efforts of various interconnected links in the supply chain (Fruit and Essentials 2020). Fresh products have high perishability, with their deterioration process starting after harvesting and progressing until complete spoilage, making waste reduction and disposal avoidance key components of fresh product supply chain strategies. The quality of food products continuously changes as they move along the supply chain, which can have significant social, economic, and environmental implications (He, Huang et al. 2018). Therefore, the entire agricultural product supply chain from the farm to the consumers seeks programs and opportunities to reduce waste. According to a report from the Natural Resources Defense Council, approximately six billion pounds of fruits and vegetables are lost each year in the United States. Some of these fruits and vegetables are discarded simply because they do not have an appealing appearance, leading to waste either at the retail level or at the consumer level (Fallah, Makhtumi et al. 2016). The fruits and vegetables sector in Iran is a valuable treasure, characterized by diverse varieties, excellent local flavors, and high quantity and quality. In fact, Iran's plateau location, its vast area, the presence of the Alborz Mountains in the north, Zagros Mountains in the west, and eastern and central mountains, as well as the influence of the climatic patterns of the Caspian Sea, Persian Gulf, and the Sea of Oman, have led to a great diversity in climatic conditions across different regions of the country. The variation in elevation in different regions of this plateau has also contributed to significant climatic variations, ranging from cold climates in highland and mountainous regions to warm climates in low-lying areas (Sheikh Sajadieh and Ziari 2021). Therefore, horticultural products in Iran exhibit a remarkable diversity that is well suited to the various climate types present in the country (Ghasemi, KORD et al. 2023).

According to FAO statistics, Iran ranks first in fruit production in the Middle East and North Africa. The world average for fruit production is 80 kilograms per capita, while in our country, it reaches 200 kilograms per capita. Additionally, in various years, Iran holds the eighth to tenth position globally in fruit production, and according to the Ministry of Agriculture Jihad, these productions are exported to 100 countries worldwide. In the global value chain and supply, retailers hold special importance. The power of food retail chains has been steadily increasing since the early 1980s, with over 50% of fruit and vegetable purchases being made solely through large stores in Western Europe. (Iran's National Export Strategy 2021-2025) Price is becoming a significant marketing tool in retail. Pricing decisions are usually influenced by cost information and consumer buying behavior, especially in the context of offering high-quality fresh products, which is one of the most influential factors (Sabir and Farooquie 2018).

To ensure the desired quality of fresh products, the quality and characteristics of the supply chain members are crucial. The factors determining fruit and vegetable losses are strongly related to the behaviors and decision-making of producers, suppliers, retailers, and consumers (Porat, Lichter et al. 2018). Therefore, in the fresh product supply chain, demand, level of service, price, etc. depend on the freshness of the product (Xu, Cheng et al. 2015), (Giri and Sarker 2016). It is estimated that 40 to 50% of global fruit and vegetable production is lost or wasted along their supply chain (Cassani and Gomez-Zavaglia 2022). As fruits and vegetables constitute the highest share of food loss and waste at 44% by weight (Lipinski, Hanson et al. 2013). Studying their supply chain is important and essential. In one study, the supply chain of fresh products was developed, including a supplier and a retailer with two different models: pull and push. Their goal was to evaluate the chain's profitability in different power structures. The study used the Stackelberg equilibrium model, with the supplier as the leader and the retailer as the follower (XIAO, Jian et al. 2008). In another study, the supply chain structure involves providing fresh products (both qualitatively and quantitatively) from a producer to a buyer, and the buyer sells the product after packaging (Cai, Chen et al. 2013), (Xu, Cheng et al. 2015).

In addition, price plays a significant role in determining the quantity of goods and/or services that consumers are willing and able to purchase (Ziari 2024). An increase in the price of a product leads to a decrease in consumer demand. Regarding fresh products, previous studies indicate that consumer response to price changes for fresh fruits and vegetables is generally low, meaning that the change in demand is less than the change in price (Gumarikiza and Curtis 2013). In general, pricing fresh products and planning and designing the sales mechanism are among the primary concerns of fruit retailers because customers are inclined towards products that are fresher and of better quality at the same price. The objective of this article is to design a model for fruit pricing in retail as an optimization problem. This modeling significantly impacts retailers in decision-making regarding order quantity, inventory management, and product quality, aiming to reduce waste. In general, the key innovations of this article can be summarized as follows:

- Pricing of fresh products, particularly fruits
- Consideration of the price-dependent demand function, product freshness, and market size
- Inclusion of suppliers, retailers, processing industries, and disposals simultaneously in problem modeling

The supply chain of fresh products not only plays a significant role in the health of society but also impacts the economic growth and independence of nations. What is important is the role of freshness degradation along the supply chain of fresh products, which results in the loss of natural resources and energy that contribute to their growth and development. Therefore, making decisions that reduce the loss of freshness and increase sales of products, thereby decreasing waste due to unsold items or loss of freshness, is vital. The pursuit of freshness, appropriate pricing strategies, and the establishment of centers that create value from products that have been damaged or have deteriorated due to aging are among the most important viewpoints of this article. This study examines a mathematical model for pricing design in the supply chain of fresh products, considering a demand function dependent on freshness and price to enhance retailer profits. To reduce waste, our objective function focused on minimizing discarded products. The epsilon constraint approach was also employed to achieve a single-objective formulation of the objective function, followed by an exact solution and case study data for extracting results and evaluating the proposed model. According to the results, using conversion centers and appropriately pricing fresh products significantly increases retailer profits, reduces waste, and enhances service quality, while also improving efficiency and conserving natural resources.

This article continues by discussing the literature of pricing in the supply chain and fresh products in Section 2. Section 3 presents the modeling problem of pricing fresh products, and Section 4 provides numerical examples to illustrate the model. Finally, in Section 5, we involve the results and future studies.

Literature Review

In this section, we review the most related researches in order to provide an overview on the relevant literature.

- **Fresh Products (Fruits) Models**

Fruits and vegetables are among the perishable products that lose their freshness over time until they reach the threshold of spoilage, meaning they gradually deteriorate until they eventually perish (Coelho and Laporte 2014). A natural deterioration process renders some products unsellable as they become completely damaged. Additionally, external factors such as improper handling, severe weather conditions, rain, and insect infestations during storage can cause damage to certain products. Therefore, fresh product retailers must manage three types of products in their stores: quality products, defective products, and damaged products (Hasan, Mashud et al. 2020). Fresh fruits and vegetables are very important for human health. Their fibrous structure and high nutritional value are essential for people's well-being. Recent studies aimed at reviewing the current status of knowledge and practices related to the fresh fruit and vegetable supply chain (FFVSC) can be found in (Tort, Vayvay et al. 2022).

Since freshness is an indicator of the quality of fresh produce, consumers usually pay more attention to it and may not be inclined to buy fresh foods that are close to losing their freshness. Therefore, retailers face significant pressure in selling fresh foods. Freshness is the primary signal of the quality of fresh food, and moreover, the sales period of fresh products is relatively short. Thus, freshness is another key factor that influences the demand for fresh food products besides price. However, there is limited research focusing on freshness and price of fresh food, which is sensitive for both retailers and consumers (Liu, Zhao et al. 2019). One of the most important complexities related to the supply chain of fresh products is the focus on their freshness and quality. Because customers tend to seek higher-quality products and demand moves in that direction, the demand function should encompass freshness and quality. Based on this, fruit and vegetable retailers need more dynamic strategies to provide satisfaction and retain customers. Purchasing, storing, disposing, and labeling are various activities carried out in a retail setting for selling fruits and vegetables. These factors directly or indirectly impact the profitability of retailing. Therefore, proper control over these factors should be the primary goal of fresh product retailers. The profitability of retailing depends on the number of units purchased and the volume of fruits and vegetables stored, as the concern for fruit and vegetable retailers is excess inventory and the risk of spoilage over time. Therefore, efforts to increase sales are accompanied by appropriate pricing strategies (Sabir and Farooquie 2018). Cai, Chen et al. (2010) determined the optimal order quantity for retailers, the level of effort to maintain freshness, the selling price, and the wholesale price of fresh products. A supply chain is considered in which a producer supplies a fresh product to the market through a third-party logistics provider, and then a distributor purchases it and sells it to end customers (Cai, Chen et al. 2013).

- **Fresh Product Supply Chain Management Models**

The complexity of modeling fresh product supply chains is due to their perishability. For example, in a supply chain, demand, service levels, pricing, etc., can depend on the freshness of the product. The literature related to the management of perishable items in supply chains, especially fresh products, is rich, and most past research focuses on pricing, quality preservation efforts, and supply chain coordination. Nakandala, Lau et al. (2021) investigated pricing strategies for variable quality fresh products over time in different market structures.

Fan, Xu et al. (2020) combined consumer selection behavior into dynamic pricing strategies for various categories of fresh agricultural products in real-time freshness. Ensuring the desired quality of fresh products, the quality, and characteristics of the members of the supply chain are crucial. For example, Dye and Yang (2016) and Li, He et al. (2019) compared the freshness of products in different sales models. The literature above considers the impact of efforts to maintain quality but does not include the impact of efforts to reduce quantity.

Considering the necessity of supply chain networks for seafood products in communities, Mosallanezhad, Arjomandi et al. (2023) developed a new supply chain network for fresh seafood, taking sustainability aspects into account to ideally balance the financial aspects of the network while increasing the recycling of waste products. To overcome the computational complexity of the exact solution methods, four meta-heuristic methods have been considered.

A new Closed Loop Supply Chain (CLSC) network for the walnut industry has been designed by (Salehi-Amiri, Zahedi et al. 2021) as part of the agricultural product sector. A Mixed Integer Linear Programming (MILP) model has been developed for the proposed network to minimize the overall costs of the walnut industry. The designed network considers forward and reverse flows not only to meet the demands of various markets but also to prepare returned products for second use. To solve the proposed model, a set of exact meta-heuristic, heuristic, and hybrid methods has been employed. Purnomo, Wangsa et al. (2022) considered a fish supply chain with multiple stages, including marine farms, fish ponds, warehouses, wholesalers, factories, distribution centers, fish recycling centers, animal feed markets, and distribution to multiple customers. The model employs Mixed Integer Linear Programming (MILP) to minimize total costs. The model is demonstrated with a numerical example to validate the proposed model and provide managerial insights for the relevant industry. Gholipour, Sadegheih et al. (2024) proposed a design for a Closed Loop Supply Chain (CLSC) for pomegranates. Its supply chain network is designed for multiple stages and includes producers, distribution centers, customers, factories, recycling centers (composting centers), and the final consumer of compost (compost markets). Using reverse supply chain processes, the wasted pomegranates are also converted into recycled products, including ethanol as vehicle fuel and renewable energy, as well as a type of compost processed as organic fertilizer. The goal of the proposed model is to minimize supply chain costs, reduce supply risks, and increase profits for growers and investors in the public and nonprofit agricultural sectors in Iran.

Wangsa, Vanany et al. (2023) examined a fresh food supply chain system involving multiple farmers, a single processor, several distributors, customers, and multiple periods. It presents a Mixed Integer Linear Programming (MILP) model for optimizing total costs related to purchasing, inspection, food waste, packaging, cold storage, transportation, and carbon emissions by optimizing inventory levels and product delivery. Teimoury, Nedaei et al. (2013) analyzed the supply chain of perishable fruits and vegetables. A simulation model is proposed using a system dynamics approach to examine behaviors and relationships within the supply chain and to determine the impact of supply, demand, and price interactions. The proposed model provides insights into the overall agricultural system while considering the effects of import quota policies. The aim of this research is to develop a multi-objective model to identify the best policy for the Municipal Fruit and Vegetable Organization of Tehran. Shirzadi, Ghezavati et al. (2021) presented a multi-period Mixed Integer Programming model aimed at maximizing profit for an inventory routing and recovery problem of fresh agricultural products, with an emphasis on the reuse of returned products considering the environmental aspect. In this model, costs such as transportation and maintenance costs are highlighted alongside current issues like expired products and customer dissatisfaction costs in relation to sustainability. The optimization method develops the total system costs assuming fuzzy quality levels and fuzzy maintenance costs. Finally, a numerical example, along with sensitivity analysis and managerial insights, is provided.

Gholipour, Sadeghieh et al. (2023) proposed a multi-level Sustainable Closed Loop Supply Chain (SCLSC) network for pomegranate fruit. The mathematical model is designed with the goal of providing the lowest price, maximizing response rates, and reducing costs. Considering the costs associated with the use of artificial intelligence in the production chain and in the reverse logistics sector, the transformation of pomegranate waste into recycled products, including ethanol for vehicle fuel and organic fertilizer, has been addressed. The wheat supply chain has been examined by (Pourmohammadi, Teimoury et al. 2020) where product quality must align with company satisfaction. Additionally, it has been pointed out that internal resources may not be able to meet the company's raw material needs, necessitating sourcing from outside. The presented problem is modeled under conditions of uncertainty and ultimately implemented on a real-world case. The rice supply chain was examined by (Jifroudi, Teimoury et al. 2020), considering various decisions such as transportation, supplier selection, harvesting, pest control, milling, and distribution, with the aim of maximizing profit. Their problem was formulated as a Mixed Integer Programming (MIP) model, which was ultimately implemented using real data.

Trivedi, Sohal et al. (2021) presented and optimized the apple supply chain in India in two stages. In the stated problem, they aimed to minimize costs and considered the time horizon as a single period. The main focus of this study was on the location of facilities and product allocation within the network. Mosallanezhad, Hajiaghaei-Keshteli et al. (2021) examined a closed-loop supply chain for shrimp to minimize costs. Their problem was multi-layered, consisting of various components, and it was modeled as a Mixed Integer Programming (MIP) problem. Ultimately, the problem was solved using several meta-heuristic algorithms, and the results were compared on a real-world case.

Sahraeian, Afshar et al. (2022) studied the dairy supply chain with two objectives: minimizing costs and maximizing the satisfaction of various members of the supply chain under uncertainty conditions. Product quality was the primary feature considered in this study. The issue was analyzed through implementation on real data. Salehi-Amiri, Zahedi et al. (2022) examined a multi-product and multi-market closed loop supply chain for avocados. The goal of the model presented in this research was to minimize costs and maximize job opportunities. The proposed model was implemented using GAMS software on a real case in Mexico. Finally, sensitivity analysis was conducted on some of the most important parameters of the problem, and the results were analyzed. Mehrbanfar, Bozorgi-Amiri et al. (2020) designed an efficient agricultural supply chain network considering greenhouses, farmland, processing plants, and agricultural distribution centers (farmers' markets), with a focus on sustainability aimed at minimizing costs, reducing greenhouse gas emissions, and maximizing employment. The proposed model is solved using the epsilon constraint method, and its efficiency is examined through a case study in Iran. The results of the model solution indicate that the use of various agricultural policies leads to greater productivity of agricultural land, production of higher quality products at lower costs, and conservation of environmental resources such as soil and water.

Baghizadeh, Cheikhrouhou et al. (2022) addressed a Mixed Integer Nonlinear Programming (MINLP) model with a multi-period time horizon for strawberry products. The problem was modeled simultaneously on cost objectives as well as social and environmental impacts. Finally, by implementing the problem in a real-world scenario and conducting sensitivity analysis on some important parameters, the results were analyzed. Jaigirdar, Das et al. (2023) studied a multi-layer supply chain for perishable products, considering three objectives. Their model was formulated as a Mixed Integer Linear Programming (MILP) problem and solved using CPLEX optimization software. Ultimately, they implemented the problem with real data from Bangladesh and analyzed the trade-offs between the objective functions. Wangsa, Vanany et al. (2023) modeled the fresh food supply chain by considering important supply chain components, including farms, producers, distributors, and final customers, while also addressing the characteristics of carbon emissions and food waste. They then analyzed the results through sensitivity analysis on some of the most important parameters of the issue. Purnomo, Wangsa et al. (2022) examined a multi-period and multi-layer closed-loop supply chain for fresh products, considering characteristics such as storage capacity, carbon emissions, and traceability. The proposed model aimed to minimize costs. Finally, they analyzed and investigated the relationship between costs and carbon emissions.

- **Pricing Models**

Supply Chain Management (SCM) involves various strategic, tactical, and operational decisions in which pricing is of utmost importance for decision-makers. Perhaps one of the most common uses of pricing models can be found in retail industries (Ziari, Ghomi-Avili et al. 2022). This includes pricing of fashion items (determined by the short lifespan of the specific product), books, automobiles, and mobile phones. Retailers typically offer a wide range of products to consumers and often face intense competition and unstable demands. Many pricing models in the literature have been introduced with applications in general retail industries. Pricing has long been used as a significant tool to maximize company profits (Soon 2011). In the world of commerce, price is considered a vital factor, and regular customers base their decisions on product prices. Many researchers have predicted the price factor using various inventory models. Generally, it is observed that high selling prices lead to a decrease in demand. However, reducing the selling price also has its own specific consequences. In contrast to other industries, agricultural products are not controlled by a few large suppliers and extensive factories that determine pricing for retailers and wholesalers. In Iran, the supply of fresh fruits and vegetables is available everywhere due to its climate, but there may be specific times when the supply is limited (Hasan, Mashud et al. 2020). Keyvanshokooh, Fattahi et al. (2013) utilized a dynamic pricing approach for reverse products in an integrated forward/reverse logistics network design problem. Their model was multi-layered, multi-period, and multi-product, with reverse products categorized based on their quality levels. The goal was to minimize total costs using a MIL model. Computational results showed that the dynamic pricing approach provides more acceptable solutions compared to static pricing.

Ramezani, Kimiagari et al. (2014) designed a closed-loop supply chain network using economic methodologies. Their objective was to maximize the profit function of product sales throughout the supply chain network. The selling prices of products in this study were considered certain, and the total design costs, including location, allocation, transportation costs, etc., were taken into account. They investigated the influence of four parameters: demand, selling price, and cost on network design. Khorshidvand, Soleimani et al. (2021) modeled a multi-layer supply chain network considering pricing decisions, capacity levels, and green product policies. Their objective was to maximize profit in the supply network. Liu, Liu et al. (2022) proposed a decision-making model for pricing in a closed-loop supply chain network under fuzzy demand. They formulated their model considering important decisions such as supplier selection and product flow optimization.

A fuzzy pricing problem was presented by Ghomi-Avili, Naeini et al. (2018), modeled within the framework of a green closed-loop supply chain for the filter industry under disruption. Increasing profits in the supply chain, reducing greenhouse gas emissions, and competition are the main objectives of the paper. After linearization, the KKT method and epsilon constraints were examined to present the results to managers. Ziari and Sajadieh (2022) examined a Mixed Integer Linear Programming model for optimizing supply chain decisions and pricing policies under stochastic disruptions for the glass industry. The proposed model specifies the optimal prices for both final and returned products, maximizing the chain's profit.

Liu, Liu et al. (2022) proposed one centralized model and three decentralized models for a closed-loop supply chain with fuzzy demand and varying quality levels for second-hand products in the automotive startup industry. Optimal pricing, collection ratios, and profit allocation for each model are determined through a combination of Stackelberg game theory and fuzzy set cutting methods. They examined important decisions in this model, such as supplier selection and optimizing product flows.

- **Dependent Demand Models**

The demand for fresh products generally refers to fresh fruits, vegetables, meat, poultry, eggs, and so on, which are closely related to people and are essential components of the human diet. Over the past decade, with improvements in quality of life and the pursuit of a healthy diet, the demand for fresh products has been steadily increasing (Gharavipour, Sheikh Sajadieh et al. 2024). According to the 2023 agricultural industry outlook, the global market for fresh products is expected to reach approximately $ 12 trillion by 2027. With the development of internet technology, e-commerce for fresh products is experiencing explosive growth. In the past few decades, various models for price-dependent demand have been proposed (Xiong and Zheng 2024).

In the past few decades, various models for price-dependent demand have been proposed. The simplest deterministic demand model is a linear increasing function of price, typically expressed as: $d(p) = a - bp$, where $d(p)$ is the quantity demanded, (P) is the price, (a) is the intercept, and (b) is the slope parameter and $a, b > 0; 0 \leq p \leq a/b$ (Petruzzi and Dada 1999), (Mills 1959), (Chou and Parlar 2006), (Petruzzi and Dada 1999) and (Karlin and Carr 1962). simple nonlinear model is defined as $d(p) = ap^{-b}$, where$d(p)$represents the quantity demanded, (P) is the price, (a) is a constant, and (b) is a parameter and $a > 0, b > 1$. Different types of demand models have been utilized in review articles)Huang, Leng et al. 2013(, (Dave 1991), (Chiu, Choi et al. 2011).

And to account for the demand for fresh products, other articles in the literature have been utilized (Cai, Chen et al. 2010)and (Mohammadi, Ghazanfari et al. 2018). As can be inferred from the literature review, various types of fresh product supply chain management with different structures have been studied and researched by a large number of researchers. Considering that the flow of fresh products throughout the chain is a primary concern of fresh product supply chain management, sales and pricing across the chain are also significant topics, which we encountered less frequently in the literature reviews.

Review of the literature shows that supply chain models have been extensively discussed in various industrial, service, and food sectors. However, none have examined the impact of freshness on activities at different levels such as suppliers, retailers, consumers, and the incorporation of processing industries. The supply chain of fresh products undergoes a change in nature immediately after the production and harvesting stages, with the residue being transformed into other products with nutritional value in processing industries. This creates a new chain of products for the market. Utilizing processing industries in the supply chain of fresh products is a novel structure to add value to products that have lost their freshness or do not have an appropriate physical state due to impact and pressure from harvesting and transportation. Based on the literature review, it is evident that research in the field of supply chain for fresh products has not focused on processing industries, and demand related to price and freshness of products has been considered as part of innovative models. The role of freshness in purchasing fresh products is always essential, and providing a suitable framework that includes retail pricing considering freshness, determining order quantities, and characteristics specific to the sale of fruits and vegetables was also not determined. Another crucial aspect is the impact of product freshness on market demand, where in products like fruits and vegetables, market demand is strongly dependent on product freshness, and the product's freshness is tied to its shelf life. Therefore, in this article, the design of a pricing model for fresh products with price-sensitive and freshness-dependent demand, considering suppliers, retailers, processing industries, and waste is utilized in the modeling process.

Problem Definition

This research focuses on designing the pricing of ultra-fresh products (fruits) in a supply chain comprising suppliers, retailers, processing industries, and waste, where demand is dependent on price and product freshness. Price plays a significant role in food purchasing decisions and especially in fruit procurement. Therefore, one of the major challenges for retailers is deciding on product prices so that they can sell fruits quickly, prevent them from staying and deteriorating, and attract more customers. Identifying the characteristics that influence fruit prices is essential for pricing. These characteristics include quality, demand, product freshness duration, inventory, fixed costs, order level, utilization of preservation technologies, and transportation. Since fruits are ultra-fresh products whose quality deteriorates over time, these changes have a greater impact on fruit pricing compared to other products. This research delves into the design of pricing for ultra-fresh products (fruits) using optimization models to increase retail profitability. The structure of the supply chain network is depicted in Figure 1.

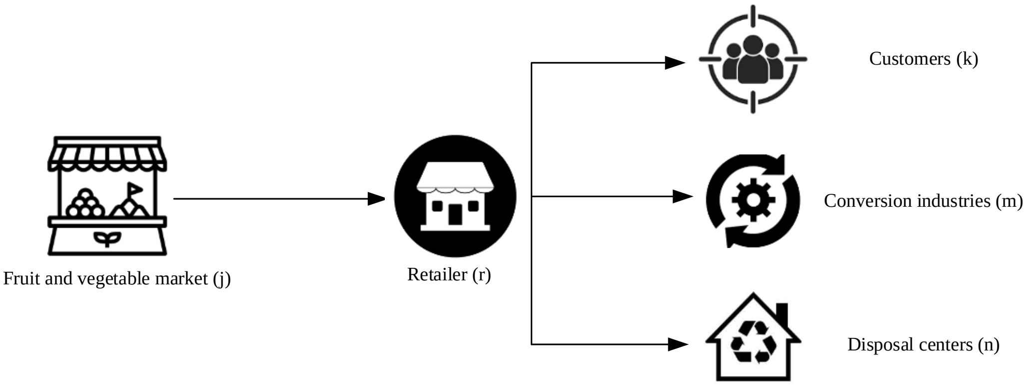

Figure 1. The structure of proposed fruit supply chain

Assumptions

The following assumptions are made through the current paper:

- The model is multi-period and multi-product.
- Shortage is incurred in the form of lost sales.
- The volume of fruit does not decrease in the case of quantitative and qualitative deterioration.
- Transportation costs from retail to the customer are not applicable unless through offline (telephone) or online sales channels.
- Remaining products at the end of the period are either transferred to the next period or sent to conversion industries or disposal centers after inspection

Considering the above explanations, the objectives of the article are to increase retail profit through appropriate pricing for different qualities of fruit, reduce product waste due to deterioration, and determine the flow amounts among centers, different levels, and customers within the supply chain. Hence, the price of fresh products and conversion industries, quantity of products among different tiers from suppliers to retailers and retailers to customers, disposal centers and conversion industries can be determined easily.

Mathematical modelling

Assume that products harvested by farmers and orchardists are ready for sale in the main fruit and vegetable market, and retailers pay transportation costs for loading from the market. The quality of products in retail is classified, and products of quality q, with a demand function d (p, t), are delivered to end customers. Products of average quality are sent for sale to processing industries (Raafat 1991). Since the price of products is crucial for processing industries, demand here is solely dependent on price. Products that have deteriorated and lost their freshness are sent to waste centers. Several functions for freshness are presented, some of which are mentioned in the literature review section. Here the retailer demand which depends on the freshness and retail price can be defined as follows: (when the product is fresh $\lambda(t) = 1$, and $0 \leq \lambda(t) < 1$ otherwise (Chiu, Choi et al. 2011) and (Dolat-Abadi 2021).

$$Dre \quad (pre, t_\theta) = \gamma_0 \ \lambda(t_\theta)\varepsilon_1(Pre \quad)^{-b}\varepsilon_2 \tag{1}$$

In equation (1), γ_0 the constant market size, $-b$ showing the customer sensitivity to the price, $\varepsilon_1$the variable over the freshness level of the product (stochastic variable influencing the product freshness), and the market demand volatility depend on each other and follow a uniform distribution in the range [0,1]. The variable (p) represents the retail price, ε_2 is demand variations that represented by the probability density function f(X) and the cumulative distribution function F(x). And, ($\lambda(t_\theta)$) represents the product freshness function, distributed in the interval (0, 1). When $\lambda(t_\theta)$ is non-zero, it indicates that the product is perishable. Since freshness is crucial for fruits, the freshness function is incorporated into the demand function. If the price of a fruit increases by one percent, demand decreases by one percent. The above items were tested across several different products, and ultimately, by extracting the mean data and output information and comparing it with the literature on the fresh products market and interviewing fresh product suppliers, important factors affecting freshness were obtained. Therefore, fresh products are price-sensitive, meaning that price fluctuations affect demand (Ghazanfari, Mohammadi et al. 2019).The other parameters using for mathematical programming will be defined, described below.

The model involves the following sets, parameters and decision variables.

Sets	
J	Set of suppliers, $j = \{1, \ldots, J\}$
R	Set of retailers, $r = \{1, \ldots, R\}$
K	Set of customers, $k = \{1, \ldots, K\}$
M	Set of conversion industries, $m = \{1, \ldots, M\}$
N	Set of disposal centers, $n = \{1, \ldots, N\}$
T	Set of time periods, $t = \{1, \ldots, T\}$
I	Set of products, $i = \{1, \ldots, I\}$
Q	Set of quality types, $q = \{1, \ldots, Q\}$

Parameters	
ta_{ijrt}^{s}	Transportation costs of fresh produced *i* from supplier *j* to retailer r at period *t* in scenario s
tb_{irmt}^{s}	Transportation costs of fresh produce *i* from retailer *r* to conversion industries *m* at period *t* in scenario s
te_{irnt}^{s}	Transportation cost of fresh produced *i* from retailer *r* to disposal center *n* at period *t* in scenario s
cbp_r	Capacity of handling fresh products at retailer *r*
cep_m	Capacity of handling quantity of not fresh produce produced at conversion industries m
fc_{rt}	Fixed costs of retailer *r* at period t
cq_{it}	The cost of determining the quality of each unit of product *i* in retailer *r* based on perceptual features and the use of sound waves
hi_{iqrt}^{s}	Product handling cost *i* at retailer *r* at period t
pw_{ijt}^{s}	The wholesale price of fresh produced *i* in supplier *j* in period *t* in scenario s
UPR	Upper bound of the retail price
UPM	Upper bound of the offered price to the conversion industries
LPR	Lower bound of the retail price
LPM	Lower bound of the offered price to the conversion industries
UDR	Upper bound of retail demand
UDM	Upper bound of conversion industry demand
γ_0	Market base demand

$\lambda^s_{it}(t_\theta)$	Product freshness function
ε_1	Random variable effecting the product freshness
ε_2	Random variable showing the demand changes
b	Price elasticity of demand
α^S_{iqmt}	Freshness elasticity of demand for conversion industries
ξ	Demand elasticity of conversion industries
Decision Variable	
PR^s_{iqkt}	Price of fresh produced i with quality q for customer k
PM^s_{iqmt}	Price of fresh produced i with quality q to conversion industry m
DR^s_{iqkt}	Demand of customer k for product i with quality q in period t in scenario
DM^s_{iqmt}	Demand of customer k for product i with quality q in period t in scenario
X^s_{iqjrt}	Quantity of fresh produced i with quality q from supplier j to retailer r at period t in scenario s
F^s_{iqrmt}	Quantity of fresh produced i with quality q shipped from retailer r to customer zone k at period t in scenario s t
R^s_{iqrnt}	Quantity of fresh produce i with quality q shipped from retailer r to conversion industry m at period t in scenario s
U^s_{iqrnt}	Quantity of fresh produce i with quality q shipped from retailer r to disposal center n at period t in scenario s
QI^s_{iqrt}	Inventory level of fresh produce i with quality q in retailer r at the end of period t in scenario s

Now, the model can be formulated as follows.

$$\begin{aligned}\text{Max}\,\Omega \;=\; &\pi_s((\sum_i\sum_q\sum_k\sum_t\sum_s PR^s_{iqkt}\,DR^s_{iqkt} \\ &+\sum_i\sum_q\sum_m\sum_t\sum_s PM^s_{iqmt}\,DM^s_{iqmt}) - (\sum_i\sum_j\sum_r\sum_t\sum_s pw^s_{ijrt}\,X^s_{ijrt} + \\ &\sum_i\sum_j\sum_r\sum_t\sum_s ta^s_{ijrt}\,X^s_{ijrt} + \sum_i\sum_r\sum_m\sum_t\sum_s tb^s_{irmt}\,R^s_{irmt} + \\ &\sum_i\sum_r\sum_n\sum_t\sum_s te^s_{irnt}\,U^s_{irnt} + \sum_i\sum_q\sum_r\sum_t\sum_s hi^s_{iqrt}\,QI^s_{iqrt} + \\ &\sum_i\sum_q\sum_r\sum_t\sum_s cq^s_{iqrt}\,X^s_{ijrt} + \sum_i\sum_q\sum_r\sum_t\sum_s cq^s_{iqrt}\,QI^s_{iqrt} \\ &+\sum_r\sum_t\sum_s fc^s_{rt}))\end{aligned} \tag{2}$$

$s.t.$

$$\sum_r F^s_{iqrkt} = \sum_k DR^s_{iqkt} \qquad \forall i,q,t,s \tag{3}$$

$$\sum_r R^s_{iqrmt} = \sum_m DM^s_{iqmt} \qquad \forall i,q,t,s \tag{4}$$

$$\sum_j X^s_{ijrt} = \sum_k F^s_{iqrkt} + \sum_m R^s_{iqrmt} + \sum_n U^s_{iqrnt} \qquad \forall i,q,t,s,r \tag{5}$$

$$\sum_i\sum_r R^S_{irmt} \le cep_m \qquad \forall m,t,s \tag{6}$$

$$\sum_i\sum_r X^s_{ijrt} \le cbp_r \qquad \forall r,t,s \tag{7}$$

$$QI^s_{ri,t-1} + \sum_j X^s_{jrit} - \sum_k F^S_{rkit} - \sum_m R^S_{rmit} - \sum_n U^S_{rnit} = QI^s_{rit} \qquad \forall i,t,s,r \tag{8}$$

$$\sum_k F^S_{rkit} + \sum_m R^S_{rmit} + \sum_n U^S_{rnit} \le QI^s_{ri,t-1} + \sum_j X^s_{jrit} \qquad \forall i,t,s,r \tag{9}$$

$$DR^s_{iqkt}(pr,t) = \gamma^s_0\lambda^s_{it}(t_\theta)\varepsilon_1(PR^s_{iqkt})^{-b}\varepsilon_2 \qquad \forall i,q,t,s,r,k \tag{10}$$

$$DM^s_{iqmt} = \alpha^S_{iqmt} - \xi PM^S_{iqmt} \qquad \forall i,q,r,t,s,m \tag{11}$$

$$F^s_{iqrkt}, R^s_{iqrmt}, U^s_{iqrnt}, X^s_{ijrt}, QI^s_{iqrt}, H^s_{iqmt}, G^s_{iqkt}, PR^s_{iqkt}, PM^S_{iqmt} \ge 0 \qquad \forall s,i,q,r,k,t,m,n \tag{12}$$

The objective function (2) is to maximize retail profit with appropriate pricing throughout the product's freshness lifespan. In the event of a scenario, the retail profit objective function equals the total revenue from product sales, which includes the volume of newly purchased products by the end customer - the first term and the conversion products - the second term, minus the costs incurred on retail sales, including the third to ninth terms. The third includes the costs of purchasing fresh products in bulk from suppliers for retail. Transporting fresh products from suppliers to retailers, and then from retailers to conversion industries and disposal centers are covered in terms four to six. In addition, the costs related to maintaining remaining products in term seven, fixed costs, and daily inspection costs of products for their classification for sale (both for new products and products remaining from the previous period) refer to terms eight and nine.

Constraints (3) states that in each time period, the existing flow from retail must meet the demand of final customers. Constraints (4) refers to the demand for products that have lost their freshness, which are sold to conversion industries and meet the demand of conversion centers in each time period. Constraints (5) specifies the flow balance between retail and final customers, conversion industries, and disposal. In fact, the total volume of fruits entering retail from suppliers is equal to the sum of the volumes sent to final customers, disposal centers, and conversion industries. Constraints (6) indicates that products moving towards conversion industries should be less than the capacity of that center mentioned in constraint four. Constraints (7) states that the amount of product coming from various suppliers is less than the retail capacity. The inventory constraint is mentioned in equations (8)-(9). The remaining product inventory at the end of the period in retail is less than its capacity. As mentioned in the problem definition, the demand for fresh products reaching final customers is based on price and freshness in constraints (10) and for remaining products for sale to processing industries, constraints (11) show that the demand depends on the product price. Finally, constraints (12) determine the domain of decision variables.

Model Linearization

Various methods can also be mentioned for linearizing functions that multiply two or more variables in each other, and the model takes a nonlinear form (Gumarikiza and Curtis 2013). In this research, for linearization, first a lower bound and then an upper bound for each of the multiplicative variables can be considered based on the demand in retail sales of fresh products and/or historical data for estimating the average (Kolodziej, Castro et al. 2013). However, with an appropriate and simple method, the model can be solved without pricing conditions and market-based demand, and then pricing variables and constraints are added to the simple model. Based on this, optimal values do not improve by adding additional constraints, so the optimal values of the simplified model can be used as the proposed new model limit. McCormick Envelopes is used to linearize the developed model in the current paper (Raghunathan, Cardonha et al. 2022), (Najman, Bongartz et al. 2021). As $DR^{s}_{iqkt} \times PR^{s}_{iqkt}$ and $PM^{S}_{iqmt} \times DM^{s}_{iqmt}$ make the objective function non-linear, the model is not in the linear form. Many approaches exist to linearize the non-linear model. Nonlinear expressions are replaced with continuous variables:

$$0 \leq DR^{s}_{iqkt} \leq UDR \tag{13}$$
$$0 \leq DM^{s}_{iqmt} \leq UDM \tag{14}$$
$$LPR \leq PR^{s}_{iqkt} \leq UPR \tag{15}$$
$$LPM \leq PM^{S}_{iqmt} \leq UPM \tag{16}$$

Finally, the following constraints are added to the problem to linearize them using McCormick relaxation. Then, the nonlinear expressions must be replaced with continuous variables in the equation, and afterwards the following constraints are added to the model:

$$G_{iqkt}^{s} = DR_{iqkt}^{s} \times PR_{iqkt}^{s} \quad \forall i,q,k,t,s \quad (17)$$

$$UPR \times DR_{iqkt}^{s} + UDR \times PR_{iqkt}^{s} - UPR \times UDR \le G_{iqkt}^{s}$$
$$G_{iqkt}^{s} \le UDR \times PR_{iqkt}^{s} + UPR \times DR_{iqkt}^{s} \quad \forall i,q,k,t,s \quad (18)$$

$$H_{iqmt}^{s} = PM_{iqmt}^{S} \times DM_{iqmt}^{s} \quad \forall i,q,m,t,s \quad (19)$$

$$UPM \times DM_{iqmt}^{s} + UDM \times PM_{iqmt}^{S} - UPM \times UDM \le H_{iqmt}^{s}$$
$$H_{iqmt}^{s} \le UDM \times PM_{iqmt}^{S} + UDM \times DM_{iqmt}^{s} \quad \forall i,q,m,t,s \quad (20)$$

Thus, the linearized model can be presented as follows:

$$\begin{aligned} Max\, \Omega \ = \ & \pi_s(\sum_i \sum_q \sum_r \sum_k \sum_t \sum_s G_{iqkt}^{s} + \sum_i \sum_q \sum_r \sum_m \sum_t \sum_s H_{iqmt}^{s}) - \\ & (\sum_i \sum_j \sum_r \sum_t \sum_s PW_{ijrt}^{s} X_{ijrt}^{s} + \sum_i \sum_j \sum_r \sum_t \sum_s TA_{ijrt}^{s} X_{ijrt}^{s} + \\ & \sum_i \sum_r \sum_m \sum_t \sum_s TB_{irmt}^{s} R_{irmt}^{s} + \sum_i \sum_r \sum_n \sum_t \sum_s TE_{irnt}^{s} U_{irnt}^{s} + \\ & \sum_i \sum_q \sum_r \sum_t \sum_s HI_{irt}^{s} QI_{iqrt}^{s} + \sum_i \sum_q \sum_r \sum_t \sum_s CQ_{iqrt}^{s} X_{ijrt}^{s} + \\ & \sum_i \sum_q \sum_r \sum_t \sum_s CQ_{iqrt}^{s} QI_{iqrt}^{s} + \sum_r \sum_t \sum_s FC_{rt}) \end{aligned} \quad (21)$$

$s.t.$

$$\sum_r F_{iqrkt}^{s} = \sum_k DR_{iqkt}^{s} \quad \forall i,q,t,s \quad (22)$$

$$\sum_r R_{iqrmt}^{s} = \sum_m DM_{iqmt}^{s} \quad \forall i,q,t,s \quad (23)$$

$$\sum_j X_{ijrt}^{s} = \sum_k F_{iqrkt}^{s} + \sum_m R_{iqrmt}^{s} + \sum_n U_{iqrnt}^{s} \quad \forall i,q,t,s,r \quad (24)$$

$$\sum_i \sum_r R_{iqrmt}^{S} \le cep_m \quad \forall m,t,s \quad (25)$$

$$\sum_i \sum_r X_{ijrt}^{s} \le cbp_r \quad \forall r,t,s \quad (26)$$

$$QI_{ir,t-1}^{s} + \sum_j X_{ijrt}^{s} - \sum_k F_{irkt}^{S} - \sum_m R_{irmt}^{S} - \sum_n U_{irnt}^{S} = QI_{irt}^{s} \quad \forall i,t,s,r \quad (27)$$

$$\sum_k F_{rkit}^{S} + \sum_m R_{rmit}^{S} + \sum_n U_{rnit}^{S} \le QI_{ri,t-1}^{s} + \sum_j X_{jrit}^{s} \quad \forall i,t,s,r \quad (28)$$

$$DR_{iqkt}^{s}(pr,t_\theta) = \gamma_0^s \lambda_{it}^s(t_\theta)\varepsilon_1(PR_{iqkt}^{s})^{-b}\varepsilon_2 \quad \forall i,q,t,s,r,k \quad (29)$$

$$DM_{iqmt}^{s} = \alpha_{iqmt}^{S} - \xi PM_{iqmt}^{S} \quad \forall i,q,r,t,s,m \quad (30)$$

$$0 \le DR_{iqkt}^{s} \le UDR \quad \forall i,q,k,t,s \quad (31)$$

$$0 \le DM_{iqmt}^{s} \le UDM \quad \forall i,q,m,t,s \quad (32)$$

$$LPR \le PR_{iqkt}^{s} \le UPR \quad \forall i,q,k,t,s \quad (33)$$

$$LPM \le PM_{iqmt}^{S} \le UPM \quad \forall i,q,m,t,s \quad (34)$$

$$G_{iqkt}^{s} = DR_{iqkt}^{s} \times PR_{iqkt}^{s} \quad \forall i,q,k,t,s \quad (35)$$

$$UPR \times DR_{iqkt}^{s} + UDR \times PR_{iqkt}^{s} - UPR \times UDR \le G_{iqkt}^{s} \quad \forall i,q,k,t,s \quad (36)$$

$$0 \le DR_{iqkt}^{s} \le UDR \quad \forall i,q,k,t,s \quad (37)$$

$$0 \le DM_{iqmt}^{s} \le UDM \quad \forall i,q,m,t,s \quad (38)$$

$$LPR \le PR_{iqkt}^{s} \le UPR \quad \forall i,q,k,t,s \quad (39)$$

$$LPM \le PM_{iqmt}^{S} \le UPM \quad \forall i,q,m,t,s \quad (40)$$

$$G_{iqkt}^{s} = DR_{iqkt}^{s} \times PR_{iqkt}^{s} \quad \forall i,q,k,t,s \quad (41)$$

$$UPR \times DR_{iqkt}^{s} + UDR \times PR_{iqkt}^{s} - UPR \times UDR \le G_{iqkt}^{s} \quad \forall i,q,k,t,s \quad (42)$$

$$G_{iqkt}^{s} \le UDR \times PR_{iqkt}^{s} + UPR \times DR_{iqkt}^{s} \quad \forall i,q,k,t,s \quad (43)$$

$$H_{iqmt}^{s} = PM_{iqmt}^{S} \times DM_{iqmt}^{s} \quad \forall i, q, m, t, s \quad (44)$$
$$UPM \times DM_{iqmt}^{s} + UDM \times PM_{iqmt}^{S} - UPM \times UDM \leq H_{iqmt}^{s} \quad \forall i, q, m, t, s \quad (45)$$
$$H_{iqmt}^{s} \leq UDM \times PM_{iqmt}^{S} + UDM \times DM_{iqmt}^{s} \quad \forall i, q, m, t, s \quad (46)$$
$$F_{iqrkt}^{s}, R_{iqrmt}^{s}, U_{iqrnt}^{s}, X_{ijrt}^{s}, QI_{iqrt}^{s}, H_{iqmt}^{s}, G_{iqkt}^{s}, PR_{iqkt}^{s}, PM_{iqmt}^{S} \geq 0 \quad \forall s, i, q, r, k, t, m, n \quad (47)$$

Computational Results

To describe, evaluate, and validate the proposed model, data from one of the fruit and vegetable markets in Tehran neighborhoods were used for experimentation and analysis to determine the retail prices for ten different types of fruits using the model parameters, and the model was tested. This proposed model was solved using **GAMS 24.3/CPLEX**, and the retail prices were reported based on the obtained numbers. Considering the specific problem, six suppliers, one retailer, five processing industries, two disposal centers, ten customers, ten product types, three quality grades, and one time period were considered and solved under two scenarios. The retailer aims to provide seasonal and grade A fruits to consumers and deliver products losing freshness to conversion centers for conversion into needed household items at a suitable price. Due to the high production costs of agricultural products originating from national capital and natural resources, and the significant time required for production (if harvested in season), there is a social responsibility on retailers and consumers to properly support fruits that have lost their freshness and appeal. In this regard, to conserve natural resources, reduce waste, and fulfill environmental responsibilities, retailers engage in value exchange with processing centers. The transport base cost is considered by the transportation company for each delivery, and the relevant wholesale price for each fruit is determined based on the approved market price in the central market. The freshness of products and their short selling period justify appropriate pricing for fresh products in the supply chain under market conditions.

On the other hand, by examining the retail aspects like capacity, fixed costs, and product transportation costs, a portion of the data is directly used in this problem. However, there are no historical data or specific records regarding market demand sensitivity to price available. These parameters have been set based on expert opinions from agriculture and fresh product market managers. A random variable affecting the freshness index of the product is assumed to have a uniform distribution between zero and one, with a fresher product gravitating towards one. Demand fluctuations have a uniform distribution between zero and one, with a demand price elasticity of one unit for fresh products. The market size varies for different types of fruits. Conversion industries may produce lemonade, syrup, jams, pickles, pomegranate paste, and tomato products. The sale of fruits that have lost their freshness depends on their price and is typically sold in bulk quantities. To define how the model solved, it can be stated that in the opposing sets (i, q, j, r, k, m, n, t) mentioned in the model, for example, the value (5, 2, 4, 1, 9, 1, 1, 1) indicates five product types with two quality grades, four suppliers, one retailer, one processing industry, and one disposal center within a time period. The model has been solved using random data, and sensitivity analysis has been performed on it.

Sensitivity Analysis

By altering various parameters of the problem that play a significant role in the model and investigating their impact on the optimal solution, several sensitivity analyses on the parameter values in the model have been conducted. Given the nature of the problem, which aims to appropriately price fresh products in retail and seeks to maximize the profit of the retailer, the capacity of the retail outlet plays a crucial role in the proposed system. Wholesale prices and the freshness rate of the product are other important parameters of the problem that influence the model. The wholesale price considered by suppliers is a factor that affects the purchasing power of the retailer and subsequently impacts customers. The proposed model has been solved using data, and the wholesale price values for each of the products are specified. For solving the model in different scenarios, the expected values of the retail price, processing industries, and the average profit for each of the products are reported in Table 1.

Table 1. Results of analyses on model

Products	Wholesale price (Thousand Rials)	Average retail price (Thousand Rials)	Average conversion industry price (Thousand Rials)	Average total profit (Million Rials)
Type 1	250	317.5	62	1896.807
Type 2	140	180.6	37	1062.212
Type 3	850	1139	212.5	6449.144
Type 4	550	726	136.5	4172.976
Type 5	250	327.7	57.5	1896.807
Type 6	380	502.4	102.6	2883.147
Type 7	320	433.8	83.2	2427.913
Type 8	180	241.9	39.9	1365.701
Type 9	290	396.1	61.2	2200.296
Type 10	470	623	109.3	3565.997

Retail Capacity

Increasing capacity and product diversity attracts customers, but to what extent can this increase be influential in improving profit. With a ten percent increase in retail capacity, a noticeable change in retail profit does not occur (around 0.15 percent), but if we increase this capacity from ten to forty percent, significant changes averaging about 6.39 percent in retail profit occur, with its steep slope indicating remarkable impacts on the current situation.

Considering the capacity increase graph, after surpassing forty percent and up to around 50 percent, it follows a slower slope, indicating that further capacity increase does not yield significant returns for retail and stabilizes as depicted in the graph after fifty percent. It is worth mentioning that increasing retail capacity also incurs additional costs, and if retail management decides to increase retail capacity, it is advisable for this increment to range between twenty to forty percent to achieve suitable profits for the retailer. However, as mentioned, gradually with further increases, this efficiency coefficient diminishes as there are limitations in the model such that exceeding fifty percent does not have any impact on demand and consequently on supply chain profit. This phenomenon is observable in the Fig 2.

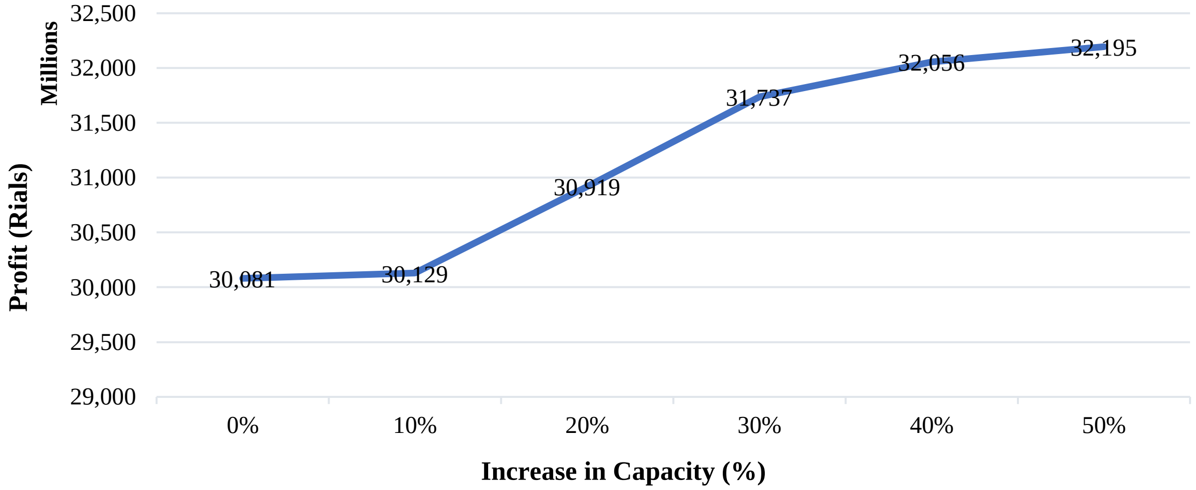

Figure 2. Analysis on retail profit increasing retail capacity

Product Freshness Rate

As it is evident in the figure below, when a product is fresh at the beginning of the sales time and freshness diminishes over time, the demand for it decreases and the objective function is at its maximum. Considering the time and loss of freshness of the product, the demand decreases, leading to a reduction in retail profit. The decrease in the objective function occurs due to the proportional decrease in freshness. Referring to the Fig 3, by reducing the freshness coefficient of the product, the demand function for the products shifts more, and the returns for products that are sent for destruction also increase at the same rate, consequently resulting in a reduction in retail profit**.**

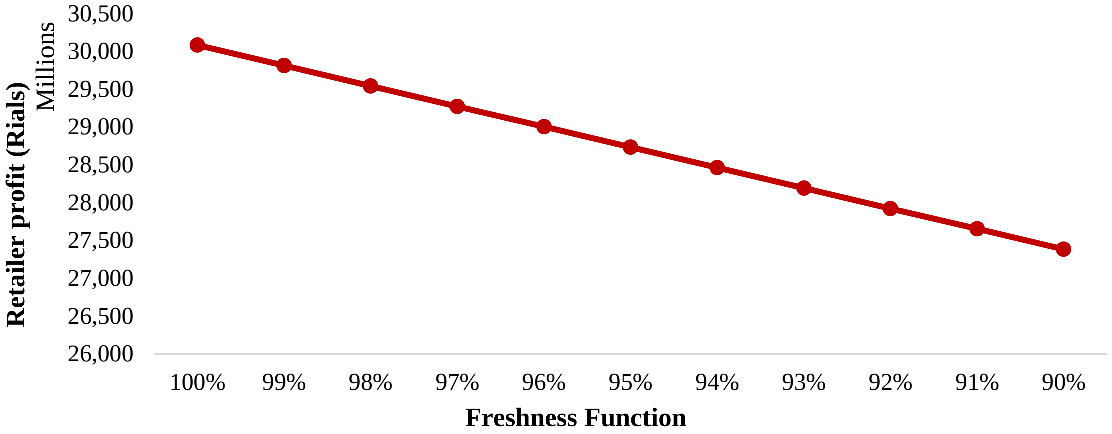

Figure 3. Analysis on retail profit changing product freshness rate

Wholesale Price

Based on market results for fresh products, especially fruits, the need for time and the use of natural energies for growth and bearing fruit is essential, and nature plays a significant role in fruit production. Long-term care by farmers, utilizing scientific methods, and being in sync with nature to bear fruit is sufficient, but what is necessary for fruit sales after harvest is its supply to customers with minimal damage and at a very fast rate, so that the fruit with good taste and quality reaches the market quickly and at a reasonable price. Harvested products are initially taken to central markets to be prepared for distribution to retailers. Since most of the supply chain costs are related to procurement, logistics, and storage, wholesale pricing plays a crucial role in determining retail prices and, consequently, impacts market demand. A change in wholesale pricing can greatly affect profits; a 10% increase in wholesale prices reduces retail profits by 1.08% with steep slope, meaning that the more the wholesale price percentage increase, the more the decrease in retail profits. However, this decrease from the initial 10% wholesale price increase is not linear; it continues to decrease from 10% slope to 50% at a rate of 2.69%. These changes are clearly visible in Fig 4.

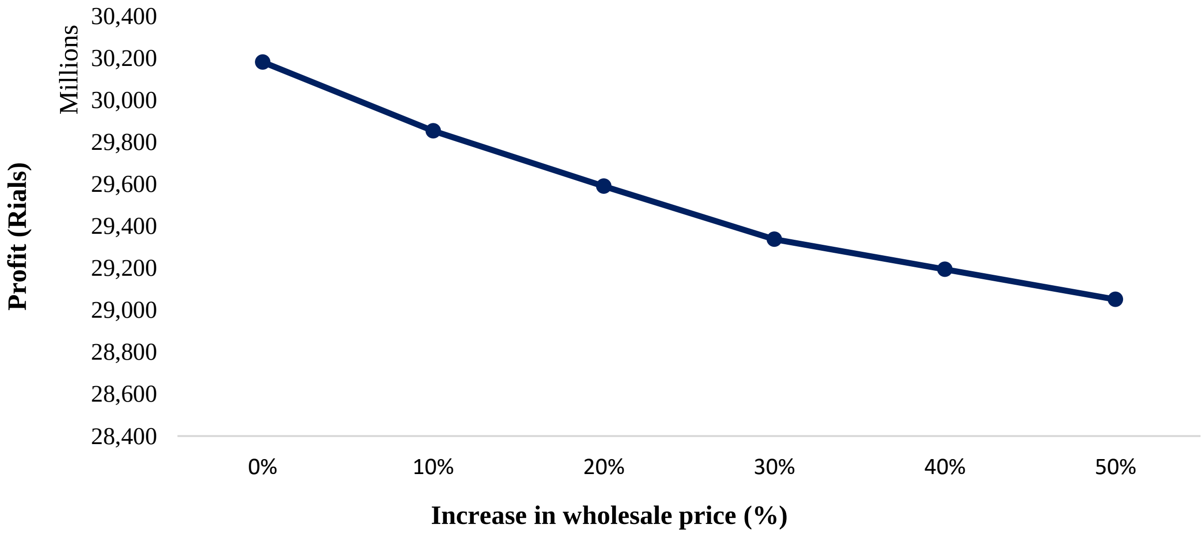

Figure 4. Analysis on retail profit changing wholesale price

Conclusions and Future Research Directions

In this article, the pricing of fresh products is modeled for the first time in the fruit supply chain considering the price-demand function dependent on freshness. An important reference of this issue is the conversion industries where products that are losing their freshness and quality are sent for sale and value creation. Fresh products lose their freshness immediately after being harvested from farms and orchards due to biological behaviors that occur in them. Fruits have a long production cycle generally lasting one year and a short supply cycle. After being sent to suppliers and then to retailers, they are divided into quality categories and sold to end customers. Products that are not fresh in terms of quality are sent to processing centers to create value, such as dried fruits, vinegar, various types of sauces, and jams. Products that are not suitable for sale to end customers and processing industries are disposed of. Retailers in fruit and vegetable markets implement appropriate pricing strategies by examining the quality of fruits over their lifespan and prepare products that are on the verge of deterioration for sale to processing industries or for disposal. The use of retailer data helped apply suitable pricing and ensure that the obtained data aligns with the retailer data. This paper focuses on products whose freshness is declining (such as vegetables and fruits). In fact, the quality of these products decreases over time, as they may suffer physical damage along the supply chain or be exposed to insect infestations. In this paper, we aim to ensure that products reach centers that create value before they reach the end of their useful life; otherwise, they are discarded. Another type of fresh product (such as milk) is a specific case where the value remains unchanged until the end of its useful life, meaning it has a fixed lifespan and spoils after its expiration date.

For better analysis, data from 10 types of fruits at a local Tehran neighborhood retail store was used and the results were reported. This article presents the forward supply chain issue alongside the concepts of freshness and quality, where demand is dependent on the freshness and price of the product. A non-linear programming was conducted to determine the price, and analyses were performed to enhance the model's efficiency using linearization techniques. Considering the inherent differences in types of fruits and the diverse productions that occur based on the nature and weather conditions for fresh products, the assumptions made are crucial for optimizing the chain with appropriate scales for improvement. It has been shown that by selling products in processing centers, retail profits increase while waste decreases. This is while reducing waste is one of the most important efforts made to reduce environmental pollution, as waste disposal is a significant and increasing operational cost for the industry.

For future results, uncertainties existing in the market and demand can be considered. Robust optimization is also can be applied to deal with uncertainties by providing flexibility and better handling capabilities. Freshness is a criterion that can have an impact on demand quantities by estimating its approximate time. Utilizing retail competitors and the scenarios that unfold are other aspects that can be beneficial for further research.

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