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Research Article

Pricing and Ordering Strategies for Fresh Food Based on Quality Grading

Yong He,[1] **Yongmei Xie**,[1] **Xiaoli Zhou**,[1] **Henry Xu**,[2] **and Yanan Yu**[1]

[1]*School of Economics and Management, Southeast University, Sipailou 2, Nanjing 210096, China*
[2]*UQ Business School, The University of Queensland, Brisbane, Queensland (QLD) 4072, Australia*

Correspondence should be addressed to Yong He; hy@seu.edu.cn

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Fresh food quality grading is the basis of fresh food marketization. On the one hand, it can effectively improve the market efficiency of fresh food and improve the earnings of retailers. On the other hand, it can alleviate the incompleteness of market information and help consumers better identify the quality characteristics of fresh food. To address the issue of quality grading for fresh food, this study constructs a retailer profit model for selling fresh food with two quality grades. Considering the quality level distribution of fresh food and based on the quality selection model, the retailer's optimal grading, pricing, and ordering of fresh food are studied. Through numerical simulation and sensitivity analysis, some conclusions with managerial implications are drawn. We find that the retailer has the optimal quality grading strategy for fresh food, which is influenced by the minimum quality level and the unit cost of fresh food. Raising the quality standard at the lowest level or reducing the unit cost can help the retailer increase the profits.

1. Introduction

Food quality is becoming an increasingly important issue in our lives. Fresh food differs in appearance, size, color, defect degree, and other quality characteristics. For example, apples have different diameters. If a retailer adopts mixed packaging and mixed sales of fresh food, it is not beneficial to his sales nor can it meet the needs of consumers with different quality preferences. Moreover, shoddy products will directly affect consumers' satisfaction with fresh food and their purchase decisions in the mixed sales mode. Consequently, the retailer needs to consider making pricing decisions based on certain quality standards.

Consumers are willing to pay higher prices for higher quality products [1]. Big data provide companies the means of tracking customers' preferences to make a business more efficient and determines what future promotions, sales, and inventory should be brought to the fore (https://techgyo.com/using-big-data-track-customer-preferences). In the big data era, some enterprises have successfully used the grading management strategy of fresh food in real commercial operations and realized income growth. For example, Pagoda and Yonghui Superstores in China have practiced fresh food gradation. For the same batch of cherries, Pagoda first divides cherries into three grades based on fruit diameter and then further separates each of the three grades based on three quality characteristics (hardness, sugar acidity, and freshness), leading to nine grades in total. Similarly, Yonghui supermarkets sell high quality goods at high prices and low quality goods at average prices. In Western countries, more than 70% of fresh food is sold according to national or industry standards [2]. Agriproduct grading can meet the diverse needs of consumers and can bring additional benefits to supply chain members [3, 4].

However, many retailers have not realized the importance of quality grading for fresh food. They adopt a mixed sales approach and rely on low prices to attract users. These retailers are lagging behind the current trend of the fresh food market and thus may result in a small profit or even loss. For example, at the B2B website of "Yimutian" (a fresh food information service platform), fresh food from many suppliers (farmers) is in mixed sales at a low wholesale price.

Meanwhile, little research has been performed on modeling how to determine the optimal quality grading and how the quality grading standard influences the pricing strategy for fresh food. Quality grading based on objective quality standards of fresh food is a key step for standardization. For example, enterprises can use quality standards based on product characteristics such as appearance and freshness to properly grade the quality of fresh food and quantify the corresponding consumer experience. These quality standards also have certain rules to follow. For example, the diameter of an apple tends to have a normal distribution distributed [5]. The distribution of a specific quality variable has a certain influence on the optimal quality grading standards, thus affecting retailers' purchase and pricing strategies. Based on this understanding, we study how to determine the optimal quality grading standard, pricing, and ordering strategies of fresh food based on consumers' quality preference and the quality distribution characteristics of fresh food.

This article mainly has the following contributions. First, the quality grading standard of fresh food is taken as an endogenous decision-making variable by retailers based on consumers' quality preference for fresh food. Second, we further study the retailer's pricing and ordering decisions based on quality grading standards.

Our research aims to address the following questions:

(1) How to present the demand function according to consumers' quality preference

(2) How to establish the quality grading standard of fresh food

(3) How does the optimal quality grading standard affect the retailer's decision

(4) How do the parameters and variables in the model affect the retailer's optimal pricing and ordering strategies

The rest of the study is arranged as follows. Section 2 analyzes the relevant literature. We introduce the problem description and model assumptions in Section 3, and the utility model based on quality selection describes the market demand for fresh food. Section 4 obtains the retailer's optimal decisions for pricing, inventory, and quality grading. Section 5 presents a numerical simulation. In Section 6, we draw conclusions from our findings and indicate future research directions.

2. Literature Review

This study is mainly related to three streams of literature: (1) quality grading of fresh food, (2) consumers' purchase preference, and (3) pricing and inventory strategies of fresh food.

Several researchers have studied the effects of quality grading. It is important to grade fresh food as it meets consumers' demand and preferences of different quality levels and improves the marketing efficiency of fresh food [6]. Zusman [7] proposed that fresh food quality grading is beneficial for retailers as they can use product quality grading to implement price discrimination and product differentiation and obtain monopoly profits. Zago and Pick [8] established a vertical difference model based on quality selection behavior and analyzed the impacts of the optimal production quantity, pricing, and quality grading of fresh food on producers and consumers. Some researchers studied various methods for grading product quality. Lee et al. [9] developed a machine vision system based on digital reflective near-infrared imaging that is used to detect fruit size. Hong et al. [10] used machine vision to measure the size, shape, and color of aquatic products. Baigvand et al. [11] applied an image processing algorithm to develop the machine vision for grading figs. According to the volume and maturity feature, Jadhav et al. [12] proposed a fruit grading system to reconstruct fruit volume. Deplomo et al. [13] employed image processing methods to classify the size, color, and texture of onions.

Most of the studies in this direction take the quality grading standard of fresh food as an exogenous variable for decision-making and do not explore the optimal quality grading standard. This study aims to determine the optimal quality grading standard of fresh agricultural products, which is the main contribution of this study.

With the help of the Internet and big data, companies can better understand customer behaviors and extract consumer preferences [14, 15]. Mishra et al. used data from social media (Twitter) to find consumers' purchasing preferences such as quality, taste, carbon footprint, organic/inorganic, and nutrition while purchasing beef [16]. Retailers can also predict consumers' demand preferences for fresh food of different quality grades based on past sales experience [17, 18]. In the food industry, Ma [19] established demand functions for fresh food with different quality grades based on consumers' preferences. He found that the retailer's profit is only related to the factors at the high quality level as well as ordering and preservation costs, but not to those at a low quality level. Transchel [20] analyzed the substitution situation between products of different quality levels. Chen et al. [21] suggested that managers should use consumers' preference information carefully to formulate policies. Wongprawmas and Canavari [22] used the discrete choice experiment to study the preferences of Thai consumers for food safety labels and brands of fresh food. Taking the tomato industry, for example, Yin et al. [23] studied consumers' preferences for brand, price, and safety labels based on a mixed logit model. Considering consumers' service preference, Liu et al. [24] built a three-stage dynamic game model considering the online and offline distribution of fresh food. Wang et al. [25] confirmed that the online channel has advantages of keeping the consumers loyal than the offline channel.

Customers' quality preference drives the quality grading and pricing strategy of fresh food. Although the customers' quality preference can be well captured in the big data era, little is known about how the decision of quality grading standard is related to customers' quality preference. This study contributes to the extant literature by considering customers' quality preferences when making quality grading and pricing decisions. Furthermore, we analyze the effect of the lowest product quality on the retailer's optimal decisions.

Due to the perishability of fresh food, pricing and inventory strategies are important to the retailer's profits. Akcay et al. [26] studied the joint dynamic pricing of multiple fresh products and showed that the markup of the products depends only on the total inventory. Wang and Li [27] proposed a dynamic pricing model to evaluate the quality of fresh food. Sainathan [28] considered consumer utility affected by freshness and studied the two-stage dynamic pricing and optimal replenishment strategies of fresh food. Adenso-Díaz et al. [29] proved that dynamic pricing can significantly reduce the waste of resources caused by the deterioration of fresh food. Duan and Liu [30] analyzed the effects of fresh food quality and reference price effects. The preservation technology investment and ordering policy also affect optimal dynamic pricing [31, 32]. Transchel [20] studied the inventory and pricing issues of multiquality agricultural products. Fan et al. [33] solved the dynamic pricing and replenishment problem of multibatch fresh food by using a heuristic method.

Pricing and ordering strategies for agriproducts have been extensively studied, but little has been done on modeling how the retailer determines the optimal quality grading standards and makes pricing and ordering decisions based on grading standards. Furthermore, we incorporated the consumers' quality preference for fresh food into the model, which makes this research more realistic.

3. Model Setting

3.1. Problem Description and Notations. Due to different planting conditions and growing environments, the same batch of fresh food may differ in defect degree, maturity, and appearance quality. If a retailer sells fresh food at the same price, consumers tend to buy the products with higher quality, leaving lower quality fresh food unsellable, making the retailer suffer profit loss. Therefore, the retailer needs to organise its fresh food into two or more quality grades according to a certain quality level and sell them separately to obtain higher profits [6, 7].

Before sales, the retailer purchases fresh food with quantity Q and quality level R, $R \in [r_L, 1], r_L > 0$, where r_L is the minimum quality level of fresh food, while 1 is the highest quality level. The quality level R follows a continuous random function, whose probability density function is $f(x)$ and the cumulative distribution function is $F(x)$. When sales begin, to meet consumers' different quality demands and preferences, the retailer divides fresh food into two quality grades (i.e., high and low) based on the grading standard r. When $R \in [r_L, r]$, the product is of low quality; otherwise, it is of high quality $R \in (r, 1]$. The retailer prices high and low quality fresh products at $P_i\,(i \in \{H, L\})$, respectively. To simplify the problem, we do not consider the residual value and the shortage cost after the end of the sales period. The quality grading model of fresh food is shown in Figure 1.

Table 1 provides the variables and parameters involved in this study.

Since consumers have a certain preference in purchasing products of different quality levels, we study the overall consumer demand by referring to the quality selection model according to Tirole [34]. The function of consumers' utility can be expressed as follows:

$$U_i = q_i\theta - P_i, \quad i \in \{H, L\}. \tag{1}$$

Due to the natural characteristics of fresh food, it is difficult to have a unified quality level. In addition, market information is incomplete, and consumers can only know the lowest and highest quality levels of products through part of the information disclosed by the retailer. Therefore, it is assumed that consumers use average quality levels to estimate the quality levels of high and low quality grades, i.e., $q_H = ((1+r)/2)$ and $q_L = ((r+r_L)/2)$. According to equation (1), consumer utility can be represented by

$$\begin{cases} U_H = \dfrac{r+1}{2}\theta - P_H, \\[2ex] U_L = \dfrac{r+r_L}{2}\theta - P_L. \end{cases} \tag{2}$$

3.2. Quality Grading and Profit Functions. Retailers are usually aware of the quality of the products they have purchased and can describe the product quality distribution through specific functions. According to the above problem description and hypothesis, the actual supply quantity of products with different quality grades is

$$\begin{cases} Q_H = Q\displaystyle\int_r^1 f(x)\mathrm{d}x, \\[2ex] Q_L = Q\displaystyle\int_{r_L}^r f(x)\mathrm{d}x. \end{cases} \tag{3}$$

In this study, we assume that consumers buy products with only one quality grade during the sales period, and every rational consumer will choose a product that maximizes utility. Therefore, the probability of consumers buying high quality fresh food is

$$\alpha_H = P\{U_H > U_L, U_H \geq 0\} = P\left\{\theta > \frac{2(P_H - P_L)}{1 - r_L}, \theta \geq \frac{2P_H}{r+1}\right\}. \tag{4}$$

The probability of consumers buying low quality fresh food is

$$\alpha_L = P\{U_L > U_H, U_L \geq 0\} = P\left\{\frac{2P_L}{r+r_L} \leq \theta < \frac{2(P_H - P_L)}{1 - r_L}\right\}. \tag{5}$$

The retailer makes price decisions based on the actual quantity of the two quality grades by maximizing its profit, i.e.,

$$\max \Pi = P_H \min\{Q_H, D_H\} + P_L \min\{Q_L, D_L\} - CQ. \tag{6}$$

Lemma 1. *According to the potential demand size of fresh food above, the actual demand of consumers for the two*

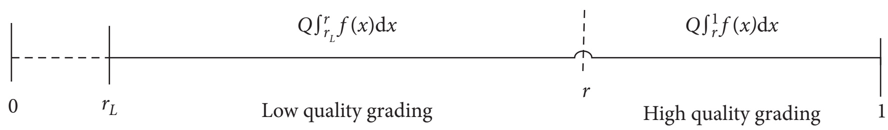

Figure 1: The quality grading model of fresh food.

Table 1: Notations description.

Notations	Description
D	Potential total demand for fresh food
r_L	The minimum quality level of fresh food
C	The unit cost of fresh food
Q	The total supply of fresh food from the retailer
r	The fresh food quality grading standard, $r \in [r_L, 1]$
P_H	Price of high quality fresh food
P_L	Price of low quality fresh food
D_i	Actual demand for fresh food with quality level i, $i \in \{\mathrm{H}, \mathrm{L}\}$
Q_i	Actual supply for fresh food with quality level i, $i \in \{H, L\}$
α_i	The probability that consumers buy fresh food with quality level i, $i \in \{H, L\}$
R	The quality level of fresh food, $R \in [r_L, 1]$
Π	Profit of the retailer

quality grades can be obtained, respectively, based on the quality selection model. Table 2 provides the actual demand for fresh food of high and low quality grades.

In Table 2, consumers' actual demand for fresh food is mainly divided into the following three situations as shown in Figure 2. They are as follows: (i) all consumers choose to buy high quality products, (ii) some consumers choose to buy high quality products and others choose to buy low quality products, and (iii) all consumers choose to buy low quality products.

4. Model Analysis

To make the research more practical, we mainly consider the situation of market demand in scenario II in Figure 2. The demand with two quality grades coexists when $(P_L/(r + r_L)) \leq (P_H/(1 + r)) \leq ((P_H - P_L)/(1 - r_L)) \leq (1/2)$.

4.1. Optimal Pricing Decision. In this situation, all consumers who choose to buy products are divided into two groups: one group chooses to buy high quality products and the other chooses to buy low quality products. Consumers' demands for high and low grade products are as follows:

$$\begin{cases} D_H = D\left[1 - \dfrac{2(P_H - P_L)}{1 - r_L}\right], \\[2ex] D_L = D\left[\dfrac{2(P_H - P_L)}{1 - r_L} - \dfrac{2P_L}{r + r_L}\right]. \end{cases} \tag{7}$$

The retailer's profit function can be expressed as follows:

$$\max \Pi = P_H \min\left\{D\left[1 - \frac{2(P_H - P_L)}{1 - r_L}\right], Q\int_r^1 f(x)\mathrm{d}x\right\} + P_L \min\left\{D\left[\frac{2(P_H - P_L)}{1 - r_L} - \frac{2P_L}{r + r_L}\right], Q\int_{r_L}^{r} f(x)\mathrm{d}x\right\} - \mathrm{CQ}. \tag{8}$$

According to equation (8), there are four types of supply and demand relations as shown in Figure 3 for fresh food of high and low quality grades.

According to Figure 3, in part 1, there is an oversupply of both high and low quality products, i.e., $Q_H \geq D_H$, $Q_L \geq D_L$. In part 2, the supply of high quality products exceeds their demand, and the supply of low quality products falls short of their demand, i.e., $Q_H > D_H, Q_L < D_L$. Part 3 shows the opposite of part 2. The supply of high quality products falls short of demand, and the supply of low quality products exceeds demand, i.e., $Q_H < D_H, Q_L > D_L$. In part 4, both high quality and low quality products are short of supply, i.e., $Q_H < D_H$ and $Q_L < D_L$.

For the convenience of analysis, we assume that the quality level of products follows the uniform distribution of $[r_L, 1]$. We find that the supply of high and low quality products can be expressed as follows:

Table 2: Actual demand for fresh food of high and low quality grades.

Conditions	D_H	D_L
$(P_L/(r+r_L)) \leq (P_H/(1+r)) \leq (P_H - P_L)/(1-r_L), 2(P_H - P_L)/(1-r_L) \geq 1$	0	$D[1 - 2P_L/(r+r_L)]$
$(p_L/(r+r_L)) \leq (p_H/(1+r)) \leq (P_H - P_L)/(1-r_L) \leq 1/2$	$D[1 - (2(P_H - P_L)/(1-r_L))]$	$D[((2(P_H - P_L))/(1-r_L)) - (2P_L/(r+r_L))]$
$(P_H - P_L)/(1-r_L) < (P_H/(r+1)) < (P_L/(r+r_L)), (P_H/(r+1)) < (1/2)$	$D[1 - 2P_H/(r+1)]$	0

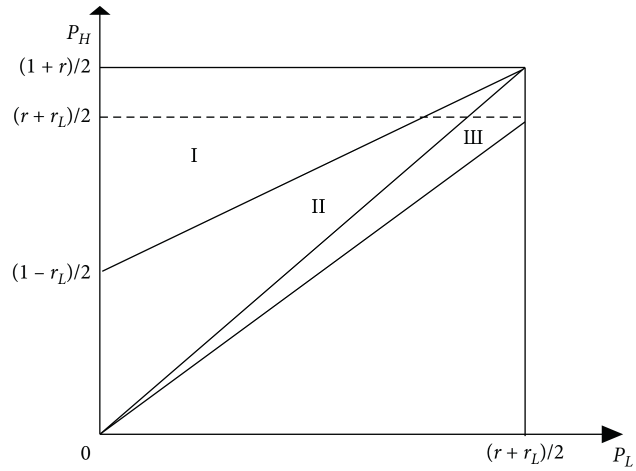

Figure 2: Actual market demand for fresh food.

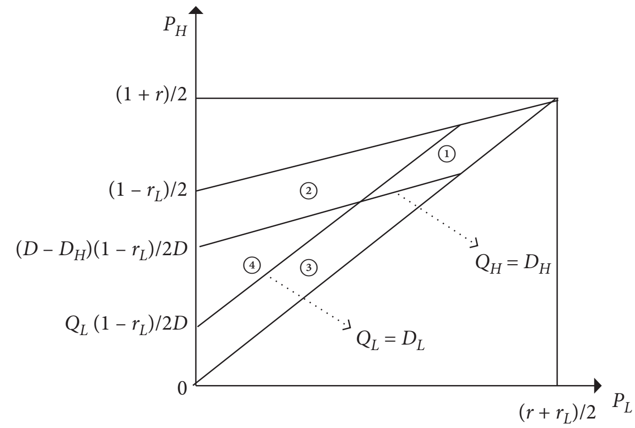

Figure 3: Supply and demand relations for fresh food.

$$\begin{cases} Q_H = \dfrac{1-r}{1-r_L}Q, \\ \\ Q_L = \dfrac{r-r_L}{1-r_L}Q. \end{cases} \tag{9}$$

Proposition 1. *When the total purchase quantity Q, potential demand size D, and grading standard R are given, the optimal pricing strategy of the retailer is presented in Table 3 and Figure 4.*

The proof of Proposition 1 is in Appendix A.

We analyze how the retailer makes pricing decisions when the demand for fresh food with both high and low quality levels coexists. According to Proposition 1, there are three optimal solutions for the retailer's optimal prices of fresh food with high and low quality grades, which are affected by the relationship between supply and demand. The prices of fresh food with high and low quality grades are positively correlated with the quality grading standard. A higher quality grading standard leads to a higher price of the product.

4.2. Optimal Ordering and Grading Decisions. The retailer needs to determine the total order quantity Q and the quality grading standard R before pricing the product. According to the above analysis, the retailer's profit function is

$$\Pi(Q,r) = \begin{cases} \dfrac{1+r}{8}D - CQ, & \dfrac{D}{2} \le Q_H \le Q, r_L \le r \le 1, \\ \dfrac{DQ(1-r_L)(1-r) - Q^2(1-r)^2}{2D(1-r_L)} + \dfrac{(r+r_L)D}{8} - CQ, & Q_H \le \dfrac{D}{2} \le Q, r_L \le r \le 1, \\ \dfrac{DQ\left(1-r_L^2\right) - \left[(1+r_L)(1-r) + \left(r^2 - r_L^2\right)\right]Q^2}{2D(1-r_L)} - CQ, & 0 < Q \le \dfrac{D}{2}, r_L \le r \le 1. \end{cases} \tag{10}$$

Proposition 2. *When the potential demand size D, minimum quality level r_L, and unit cost of fresh food C are given, the retailer's optimal quality grading standard, optimal order quantity, and profit can be expressed as follows:*

(1) When $C \le ((1-r_L)/8)$, the optimal quality grading standard and the optimal order quantity of fresh food are $r^* = \delta, Q^* = ((1-\delta)D/8C)$, respectively, and the retailer's optimal profit is $\Pi^* = ((1-\delta)^2 D/16C) - (((1-\delta)^4 D)/16C(1-r_L)) + (((2\delta + r_L - 1)D)/8)$.

(2) When $((1-r_L)/8) < C < ((1+r_L)/2)$, the optimal quality grading standard and the optimal order quantity are $r^* = ((1+r_L)/2), Q^* = ((2D(1-2C+r_L))/(3+5r_L))$, respectively, and the retailer's optimal profit is $\Pi^* = ((D(1-2C+r_L)^2)/(6+10r_L))$;

(3) When $C \ge ((1+r_L)/2)$, the optimal order quantity is $Q^* = 0$, where δ satisfies $\begin{cases} (1-\delta)^3 - 4C(1-r_L)(1-\delta) + 8C^2(1-r_L) = 0, \\ r_L \le r \le 1 - 4C. \end{cases}$

The proof of Proposition 2 is in Appendix B.

According to Proposition 2, we mainly obtain the retailer's optimal quality grading, optimal order quantity, and profit. Under different supply and demand relations, the retailer's optimal grading standard and optimal order

Table 3: The retailer's optimal pricing decision.

Conditions	P_H^*	P_L^*
$((D/2) \le Q_H \le Q)$, $(r_L \le r \le 1)$	$((1+r)/4)$	$((r+r_L)/4)$
$(Q_H < (D/2) \le Q)$, $(r_L \le r \le 1)$	$((r+r_L)/4) + ((D-Q_H)(1-r_L)/2D)$	$((r+r_L)/4)$
$(0 < Q \le (D/2))$, $(r_L \le r \le 1)$	$((D(1+r) - (1-r_L)Q)/2D)$	$((D-Q)/2D)(r+r_L)$

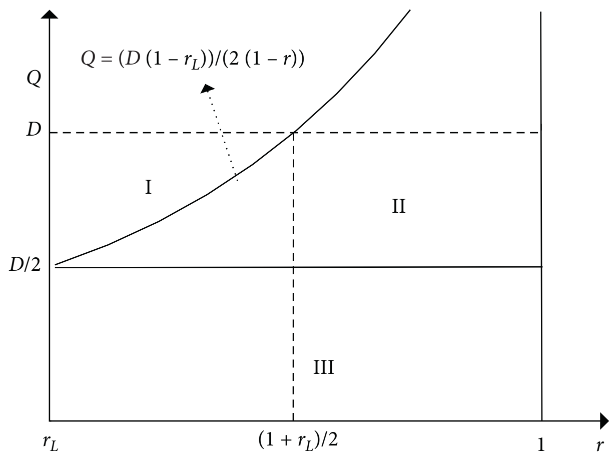

Figure 4: Retailer's optimal pricing strategy under the influence of Q and R.

quantity are affected by the unit cost of fresh food. Under different unit costs, the retailer will adjust his optimal decisions to increase profit.

Corollary 1. *(1) When $0 < C \le ((1+r_L)/2)$, the optimal quality grading standard r^* of fresh food increases with the lowest quality level r_L. (2) When $0 < C \le ((1-r_L)/8)$, the optimal grading standard r^* for fresh food decreases with the unit cost of fresh food. And when $((1-r_L)/8) < C \le ((1+r_L)/2)$, the optimal grading standard remains unchanged, regardless of the unit cost of fresh food.*

The proof of Corollary 1 is in Appendix C.

To ensure that high quality fresh food is sold at high prices and to reduce the quantity of low quality fresh food, the retailer will increase the quality grading standard as the minimum quality level of fresh food increases. However, as the unit cost of fresh food increases, the retailer will gradually reduce the optimal quality grading standard for fresh food to avoid the profit loss caused by an excessive quantity of low quality products and to ensure the profit of high quality products. When the unit cost of fresh food is high, the retailer will keep the quality grading standard unchanged to achieve a balance between the supply and demand of both high and low quality products.

Corollary 2. *When $((1-r_L)/8) < C \le ((1+r_L)/2)$, the retailer's profit π^* is positively correlated with the lowest quality level of fresh food and negatively correlated with the cost of fresh food.*

The proof of Corollary 2 is in Appendix D.

When the unit cost of fresh food is moderate, the increase of the minimum quality level of fresh food raises its price, further increasing the retailer's profit. As the unit cost of fresh food increases, the retailer will decrease the order quantity and quality grading standard to keep a balance between the supply and demand of both high and low quality fresh food. The retailer's profit falls as the unit cost rises because the increase of revenue from a higher price cannot compensate for the decrease of revenue from reduced demand.

Corollary 3. *(1) The optimal purchase quantity Q^* of fresh food is negatively correlated with the cost of fresh food. When the cost of fresh food is too high, the retailer will give up selling products with two quality grades. (2) When $0 < C \le (1/5)$, the optimal purchase quantity Q^* of fresh food decreases with the minimum quality level r_L. (3) When $(1/5) < C < ((1+r_L)/2)$, the optimal purchase quantity Q^* of fresh food increases with the minimum quality level r_L.*

The proof of Corollary 3 is in Appendix E.

Corollary 3 indicates that the unit cost of fresh food and the minimum level of quality affect the retailer's order quantity. When the unit cost of fresh food is low, with the increase of the minimum quality level, high and low quality products are more competitive and substitutable. To prevent profit loss caused by an excessive surplus of products, the retailer will reduce the purchase quantity. When the unit cost of fresh food is high, the retailer will raise its price, leading to the increase of quality grading standard. Meanwhile, the supply of high quality fresh food will decrease as the quality grading standard increases. Therefore, the retailer will gradually increase the supply of fresh food to ensure that all fresh foods can be sold at relatively higher prices.

5. Numerical Simulation

5.1. Numerical Example. To better analyze how relevant parameters affect the retailer's optimal decisions, this section assumes that the value of parameters satisfies $r_L = 0.5$, $D = 10$, and $C = 0.02$, and the product quality obeys the uniform distribution on $(r_L, 1)$. The influences of quality grading standard and order quantity on the retailer's profit are shown in Figure 5.

Figure 5 shows that the retailer's profit is a concave function of the quality grading standard and order quantity, and there is a unique and optimal solution to maximize the retailer's profit. The retailer's profit first increases and then decreases with the increase of order quantity, and the speed of increase is greater than that of decrease. When the purchase quantity is larger than the potential market demand, the retailer's profit will gradually decrease or even suffer a loss due to the increase of surplus of high and low quality fresh foods. When the purchase quantity is low, although it can avoid the profit reduction caused by the surplus, it cannot compensate for the profit reduction caused by unmet consumer demand.

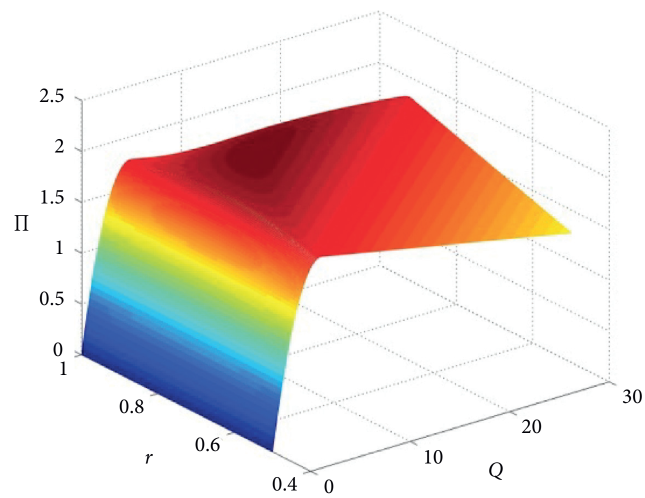

Figure 5: The influences of r and Q on the retailer's profit.

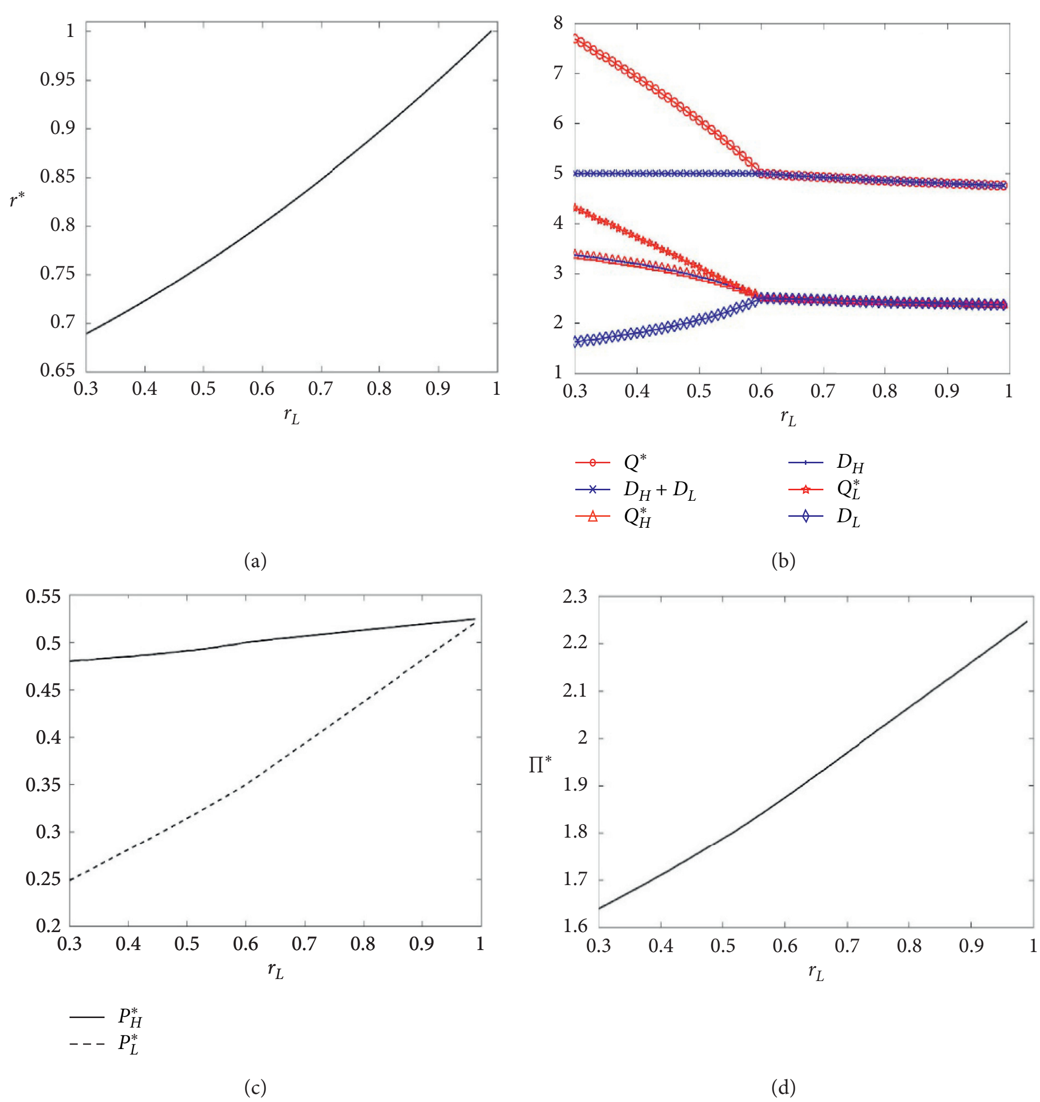

Figure 6: The influences of the lowest quality level r_L on the retailer's optimal decisions. (a) The influence of r_L on r, (b) the influence of r_L on D and Q, (c) the influence of r_L on P, and (d) the influence of r_L on Π.

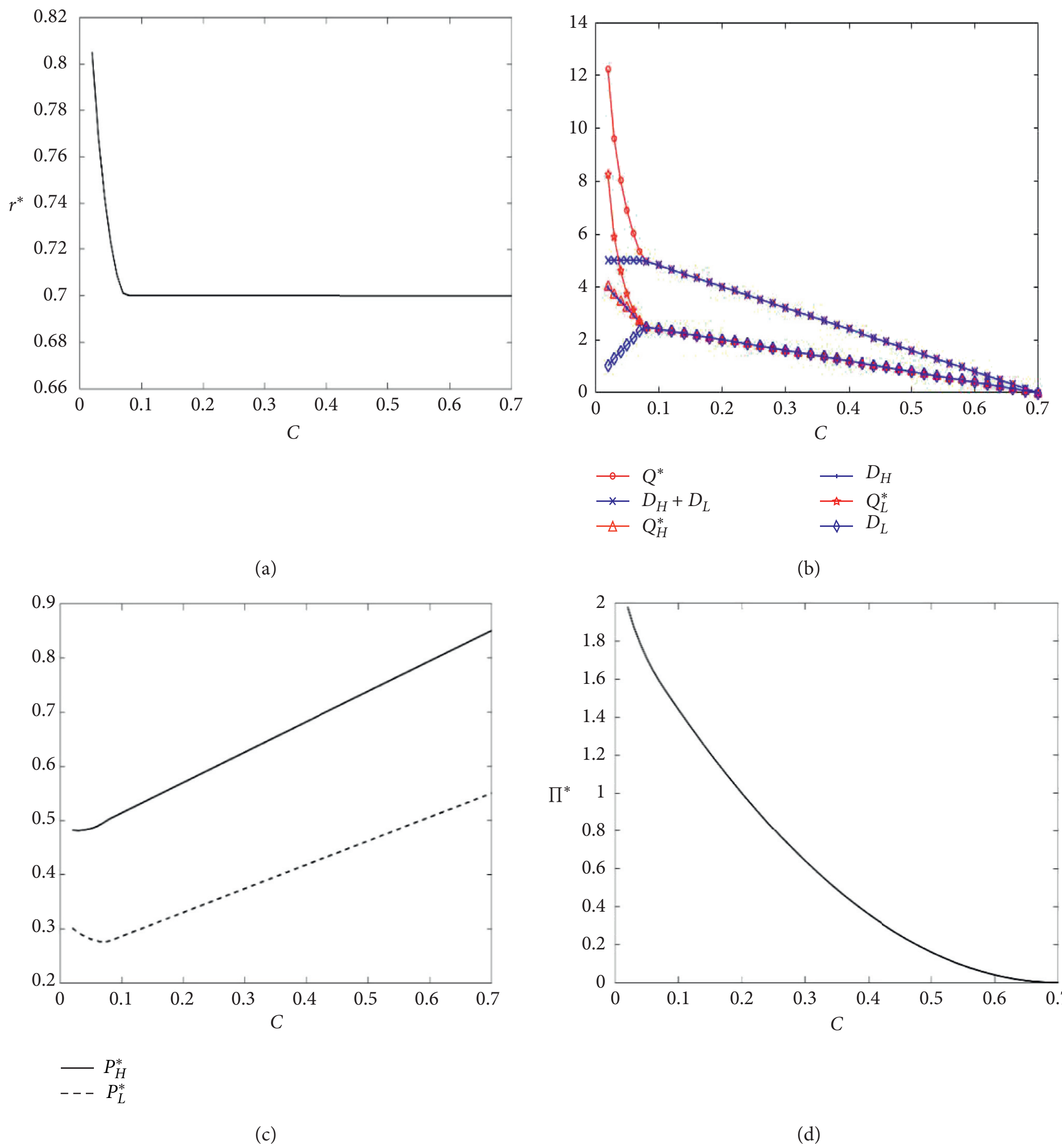

FIGURE 7: The influences of unit cost C on the retailer's optimal decisions. (a) The influence of C on r, (b) the influence of C on D and Q, (c) the influence of C on P, and (d) the influence of C on Π.

5.2. Sensitivity Analysis

5.2.1. The Influences of the Lowest Quality on the Retailer's Optimal Decisions. We set the value of parameters D and C as $D = 10$ and $C = 0.02$, respectively, and the lowest quality level r_L varies between $[0.3, 0.99]$. We obtain the optimal decisions of the retailer from Proposition 2. We mainly analyze the influences of the lowest quality level r_L on the retailer's optimal decisions as shown in Figure 6.

Figure 6 reveals that the optimal quality grading standard and selling price increase with the lowest quality level of fresh food. The selling price gap between high and low quality grades gradually narrows with the increase of r_L. Meanwhile, the total purchase amount, the supply, and the total market demand for the two quality grades are gradually decreasing. Interestingly, with the decline in the total purchase quantity of fresh food, the retailer's revenue is growing. The reason can be interpreted as follows. With the increase of the lowest quality level, the quality gap between the fresh food with two quality grades decreases, and the competition between products increases. Therefore, when consumer demand for the two quality grades declines, the retailer reduces the total order quantity accordingly. To maintain his sales profits, the retailer will raise the standards of quality grading. On the one hand, it can ensure that high quality fresh food can be sold at high prices, and on the other hand, low quality grades can guide the market demand and supply to match reasonably with a higher price.

The above analyzes indicate that when the unit cost of fresh food is constant, the retailer can increase profits by improving the minimum level of quality. Meanwhile, with the increase of the minimum quality level, the market competition of products with two quality grades is enhanced. The retailer can achieve profit growth by reducing the total order quantity with two quality grades and increase the standards of quality grading.

5.2.2. The Influences of Unit Cost on the Retailer's Optimal Decisions. First, we set the value of parameters D and r_L as $D = 10$, and $r_L = 0.4$, respectively, and r_L varies between $[0, 0.7]$. Then, we obtain the optimal decisions of the retailer via Proposition 2. And the influences of the unit cost C on the retailer's optimal decisions as shown in Figure 7.

As shown in Figure 7, with the increase of the unit cost, the prices of products with two quality grades also increase, while the total order quantity and sales profits of high and low quality grades decrease. When the cost is too high, the retailer will forgo purchasing fresh food. It is worth noting that the grading standard of the two quality grades first decreases and then remains unchanged with the increase in the unit cost of fresh food. This indicates that the retailer should be dedicated to providing more fresh food with high quality. As the retailer continues to reduce his total purchase quantity of fresh food, he cannot have the advantage of small profits but quick turnover. Consequently, the retailer can only increase the sales prices of the two quality levels to ensure profitability. With the increase in the cost of fresh food, the retailer will increase prices and adjust grading standards to avoid the surplus of the products. However, the loss from reduced supply clearly outweighs the gain from higher selling prices. As a result, the retailer's profit tends to decline. Therefore, the cost of fresh food is an important factor affecting the profitability of the retailer who can use the cost advantages of fresh food to be more competitive in the market and ensure profit growth.

6. Conclusion

Based on the above analysis, it is clear that the mixed sales mode for fresh food has a number of disadvantages. On the one hand, it is difficult to meet the needs of consumers with different quality preferences. On the other hand, the failure of selling low quality products will cause the retailer to lose profits. Due to the timeliness and perishability of fresh food, the differentiated sales mode based on quality grading of fresh food can effectively promote the sales of fresh food and reduce the profit loss caused by unsalable products.

Therefore, we consider a situation in which a retailer sells fresh food of two quality grades. That is, fresh food is divided into high and low quality grades based on its quality distribution. Considering consumers' preferences of quality levels, a quality selection model is used to describe consumers' purchase behavior. By building the retailer's profit function, we analyze its optimal purchase quantity, grading standard, pricing, and profit under the condition of quality grading, as well as the effects of the lowest quality and unit cost on the retailer's optimal decisions. The main conclusions are as follows:

(1) There is an optimal strategy for quality grading of fresh food, which is affected by factors such as the lowest quality, unit cost, and quality level distribution of fresh food. The retailer can explore the optimal quality grading strategy according to the actual situation and make pricing and ordering decisions based on quality grading to maximize his profit.

(2) When the lowest quality level of fresh food remains unchanged, the retailer's total profits may not be positively correlated with the total order quantity. For example, if the unit cost of fresh food is very low, the retailer's profit in the situation of "oversupply" may be higher than that when there is a good "balance of supply and demand."

(3) Raising the lowest quality level is conducive to increasing the retailer's profit from differentiated sales. The prices of products with high and low quality grades increase with the minimum quality level.

This study also has some limitations. First, we consider only two grades of quality (i.e., high and low), and product quality obeys uniform distribution. Nonetheless, the real situation may be more complex. For example, product quality is classified into multiple levels and has a more complex distribution. Second, we only study quality grading and pricing strategies of fresh food from the perspective of retailers. The decisions from the perspective of food supply chains by considering the interests of upstream producers are short of study. By analyzing these issues, we hope to provide retailers with some management insights and practical guidance in decision-making.

Appendix

A. Proof of Proposition 1

According to the retailer's revenue function, the retailer's optimal decision can be divided into four scenarios as shown in Figure 3. Since the optimal decision point of scenario 2, 3, and 4 falls on the boundary of scenario 1 region, only the optimal solution of scenario 1 needs to be discussed to obtain the overall optimal solution of the objective function.

Scenario 1: $\max \Pi(P_H, P_L) = P_H D[1 - ((2(P_H - P_L))/(1 - r_L))] + P_L D[(2(P_H - P_L)/(1 - r_L)) - (2P_L/(r + r_L))] - CQ$

$$\text{S.t.}\begin{cases} D\left[1 - \dfrac{2(P_H - P_L)}{1 - r_L}\right] \le Q\displaystyle\int_r^1 f(r)\mathrm{d}r, \\ D\left[\dfrac{2(P_H - P_L)}{1 - r_L} - \dfrac{2P_L}{r + r_L}\right] \le Q\displaystyle\int_{r_L}^r f(r)\mathrm{d}r, \\ \dfrac{P_L}{r + r_L} \le \dfrac{P_H}{1 + r} \le \dfrac{(P_H - P_L)}{1 - r_L} \le \dfrac{1}{2}, \quad P_H > P_L > 0, 0 < r_L \le r \le 1. \end{cases} \tag{A.1}$$

The first derivative is

$$\frac{\partial \Pi\left(P_H, P_L\right)}{\partial P_H}=\left[1-\frac{4\left(P_H-P_L\right)}{1-r_L}\right] D,$$
$$\frac{\partial \Pi\left(P_H, P_L\right)}{\partial P_L}=\left[\frac{4\left(P_H-P_L\right)}{1-r_L}-\frac{4 P_L}{r+r_L}\right] D. \tag{A.2}$$

Due to second derivative,

$$\frac{\partial \Pi^2\left(P_H, P_L\right)}{\partial P_H^2}=-\frac{4}{1-r_L}<0,$$
$$\frac{\partial \Pi^2\left(P_H, P_L\right)}{\partial P_L^2}=\frac{-4}{1-r_L}-\frac{4}{r+r_L}<0 \tag{A.3}$$
$$-\frac{4}{1-r_L} * \left(\frac{-4}{1-r_L}-\frac{4}{r+r_L}\right)-\frac{4}{1-r_L} * \frac{4}{1-r_L}=\frac{16}{\left(1-r_L\right)\left(r+r_L\right)}>0.$$

Therefore, the profit function of the retailer is the joint concave function of P_H and P_L, where the maximum value exists, and its Lagrangian function is

$$\begin{aligned}
\mathrm{L}\left(P_H, P_L, \lambda_1, \lambda_2, \lambda_3, \lambda_4\right)= & P_H D\left[1-\frac{2\left(P_H-P_L\right)}{1-r_L}\right]+P_L D\left[\frac{2\left(P_H-P_L\right)}{1-r_L}-\frac{2 P_L}{r+r_L}\right]-C Q \\
& +\lambda_1\left(Q \int_r^1 f(r) \mathrm{d} r-D\left[1-\frac{2\left(P_H-P_L\right)}{1-r_L}\right]\right)+\lambda_2\left(Q \int_{r_L}^r f(r) \mathrm{d} r-D\left[\frac{2\left(P_H-P_L\right)}{1-r_L}-\frac{2 P_L}{r+r_L}\right]\right) \\
& +\lambda_3\left(\frac{1-r_L}{2}-P_H+P_L\right)+\lambda_4\left(\frac{r+r_L}{1+r} P_H-P_L\right).
\end{aligned} \tag{A.4}$$

KKT conditions are as follows:

$$\begin{aligned}
\frac{\partial L}{\partial P_H}&=\left[1-\frac{4\left(P_H-P_L\right)}{1-r_L}\right] D+\lambda_1\left(\frac{2}{1-r_L}\right) D+\lambda_2\left(\frac{-2}{1-r_L}\right) D-\lambda_3+\lambda_4\left(\frac{r+r_L}{1+r} P_H\right)=0, \\
\frac{\partial L}{\partial P_L}&=\left(\frac{4\left(P_H-P_L\right)}{1-r_L}-\frac{4 P_L}{r+r_L}\right) D+\lambda_1\left(\frac{-2}{1-r_L}\right) D+\lambda_2\left(\frac{2}{1-r_L}+\frac{2}{r+r_L}\right) D+\lambda_3-\lambda_4=0, \\
&\lambda_1\left(Q \int_r^1 f(r) \mathrm{d} r-D\left[1-\frac{2\left(P_H-P_L\right)}{1-r_L}\right]\right)=0, \\
&\lambda_2\left(Q \int_{r_L}^r f(r) \mathrm{d} r-D\left[\frac{2\left(P_H-P_L\right)}{1-r_L}-\frac{2 P_L}{r+r_L}\right]\right)=0, \\
&\lambda_3\left(\frac{1-r_L}{2}-P_H+P_L\right)=0, \\
&\lambda_4\left(\frac{r+r_L}{1+r} P_H-P_L\right)=0.
\end{aligned} \tag{A.5}$$

Three possible solutions are obtained:

$$
\begin{aligned}
&P_H = \frac{1+r}{4}, P_L = \frac{r+r_L}{4}, \lambda_1 = 0, \lambda_2 = 0, \lambda_3 = 0, \lambda_4 = 0, \quad \text{when } \frac{D}{2} \le Q_H \le Q \le D,\\
&P_H = \frac{r+r_L}{4} + \frac{(D-Q_H)(1-r_L)}{2D}, P_L = \frac{r+r_L}{4}, \lambda_1 = \frac{(D-2Q_H)(1-r_L)}{2D}, \lambda_2 = 0, \lambda_3 = 0, \lambda_4 = 0, \quad \text{when } Q_H \le \frac{D}{2} \le Q \le D,\\
&P_H = \frac{(D-Q)(1+r) + Q(1-r_L)\int_{r_L}^{r} f(r)\mathrm{d}r}{2D}, P_L = \frac{(D-Q)}{2D}(r+r_L),\\
&\lambda_1 = \frac{(D-2Q)(r+1)}{2D} + \frac{(1-r_L)Q\int_{r_L}^{r} f(r)\mathrm{d}r}{D}, \lambda_2 = \frac{(D-2Q)(r+r_L)}{2D}, \lambda_3 = 0, \lambda_4 = 0, \quad \text{when } 0 < Q \le \frac{D}{2}.
\end{aligned}
\tag{A.6}
$$

B. Proof of Proposition 2

According to equation (10), when $(D/2) \le Q_H \le Q$ and $r_L \le r < 1$, the retailer's profit function is $\Pi = (1 + r/8)D - CQ$; due to $(\partial\Pi/\partial r) = (D/8) > 0$, $(\partial\Pi/\partial Q) = -C < 0$, and $Q_H \ge (D/2)$, the optimal solution to the retailer's profit function must fall on $Q_H = (D/2)$, i.e. $Q = ((1-r_L) * D/2(1-r))$. By Proposition 1, the retailer's profit function is a continuous differentiable function about r and Q. When $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$, the retailer's profit function is a strictly concave function about r and Q, and $(\partial\Pi/\partial r)(Q_H = (D/2)) = (D/8) > 0$. The retailer's profit in the scenario when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$ is always less than the profit in the scenario when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$.

And when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$, the optimal price for the two quality grades is $P_H^* = ((r + r_L)/4) + ((D - Q_H)(1 - r_L)/2D)$, $P_L^* = ((r + r_L)/4)$, and the retailer's profit function is $\Pi^* = ((DQ(1-r_L)(1-r) - Q^2(1-r)^2)/(2D(1-r_L))) + (((r + r_L)D)/8) - CQ$.

The Hessian matrix is

$$
H = \begin{pmatrix} H_1 & H_2 \\ H_3 & H_4 \end{pmatrix} = \begin{pmatrix} \dfrac{-2Q^2}{2D(1-r_L)} & \dfrac{4Q(1-r) - D(1-r_L)}{2D(1-r_L)} \\ \dfrac{4Q(1-r) - D(1-r_L)}{2D(1-r_L)} & \dfrac{-2(1-r)^2}{2D(1-r_L)} \end{pmatrix}. \tag{B.1}
$$

Due to

$$
\begin{aligned}
|H_1| &= \frac{-2Q^2}{2D(1-r_L)} < 0,\\
|H_2| &= \frac{-2Q^2}{4D^2(1-r_L)^2} \cdot \frac{-2(1-r)^2}{2D(1-r_L)} - \left(\frac{4Q(1-r) - D(1-r_L)}{2D(1-r_L)}\right)^2 > 0.
\end{aligned}
\tag{B.2}
$$

The Hessian matrix is a negative definite matrix, the objective function is strictly concave, and there is a maximum.

Owing to $(\partial\Pi/\partial r)(Q_H = (D/2)) = (D/8) > 0$, $(\partial\Pi/\partial r)(r = 1) = (D/8) - (Q/2) < 0 \, (Q > (D/2))$, the optimal solution of the objective function is not on the boundary of the domain $Q_H = (D/2), r = 1$. In addition, due to $(\partial\Pi/\partial Q) = -C + ((2Q(1-r)^2 + D(1-r)(1-r_L))/2D)$, when $r = ((1 + r_L)/2), Q = (D/2)$, we find $(\partial\Pi/\partial Q) + C - ((1-r_L)/8) = 0$, $(\partial\Pi/\partial r) = 0$, and if $C \ge (1 - r_L/8)$, the derivative is $\partial\Pi/\partial Q(r = (1 + r_L/2), Q = (D/2)) < 0$, $\partial\Pi/\partial r(r = (1 + r_L/2)) = 0$. At this point, the objective function achieves the optimal value at $(r, Q) = ((1 + r_L/2), (D/2))$. On the other hand, if $C < ((1 - r_L)/8)$, the optimal solution of the objective function lies within the domain. Solving for $(\partial\Pi/\partial Q) = 0$, $(\partial\Pi/\partial r) = 0$, we get the internal optimal solution is $(r^*, Q^*) = (\delta, ((1-\delta)D/8C))$, where δ meets the following conditions.

$$
\begin{cases} (1-\delta)^3 - 4C(1-r_L)(1-\delta) + 8C^2(1-r_L) = 0, \\ r_L \le r \le 1 - 4C. \end{cases}
\tag{B.3}
$$

Therefore, when $Q_H < (D/2) \le Q$ and $r_L \le r \le 1$, the retailer's optimal ordering and grading decisions are as follows:

(1) If $C \ge (1 - r_L/8)$, the optimal decisions are $r = (1 + r_L/2)$, $Q = (D/2)$, and the retailer's profit is $\Pi^* = ((5 + 3r_L - 16C)/32)D$;

(2) If $C < (1 - r_L/8)$, the optimal decisions are $r = \delta$ and $Q = ((1-\delta)D/8C)$, and the retailer's profit is

$$\Pi^* = \frac{(1-\delta)^2 D}{16C} - \frac{(1-\delta)^4 D}{16C(1-r_L)} + \frac{(2\delta + r_L - 1)D}{8}. \tag{B.4}$$

And when $0 < Q \leq (D/2)$ and $r_L < r \leq 1$, the retailer's profit function is

$$\Pi^* = \frac{DQ\left(1-r_L^2\right) - \left[(1+r_L)(1-r) + \left(r^2 - r_L^2\right)\right]Q^2}{2D(1-r_L)} - CQ. \tag{B.5}$$

According to the KKT condition, the two sets of solutions are

(1) $r = ((1 + r_L)/2), Q = (D/2), \lambda_1 = ((1 - 8C - r_L)/8), \lambda_2 = 0, \lambda_3 = 0$; the retailer's profit is $\Pi^* = ((5 - 16C + 3r_L)/32)D$, and $C \leq ((1 - r_L)/8)$;

(2) $r = (1 + r_L/2), Q = ((2D(1 - 2C + r_L))/(3 + 5r_L)), \lambda_1 = 0, \lambda_2 = 0, \lambda_3 = 0$; the retailer's profit is $\Pi^* = ((D(1 - 2C + r_L)^2)/(6 + 10r_L))$ and $C > ((1 - r_L)/8)$.

To sum up, by comparing the optimal profit values of the three subregions of the profit function, the following conclusions can be drawn:

(1) When $C \leq ((1 - r_L)/8)$, the profit function is

$$\Pi^* = \max\left\{\frac{(5 - 16C + 3r_L)}{32}D, \frac{(1-\delta)^2 D}{16C} - \frac{(1-\delta)^4 D}{16C(1-r_L)} + \frac{(2\delta + r_L - 1)D}{8}\right\} = \frac{(1-\delta)^2 D}{16C} - \frac{(1-\delta)^4 D}{16C(1-r_L)} + \frac{(2\delta + r_L - 1)D}{8}. \tag{B.6}$$

The retailer's optimal decision is $r^* = \delta$ and $Q^* = (((1 - \delta)D)/8C)$

(2) When $C > ((1 - r_L)/8)$, the profit function is $\Pi^* = \max\{((5 + 3r_L - 16C)/32)D, ((D(1 - 2C + r_L)^2)/(6 + 10r_L))\} = (D(1 - 2C + r_L)^2/(6 + 10r_L))$. The retailer's optimal decision is $r^* = ((1 + r_L)/2)$, $Q^* = ((2D(1 - 2C + r_L))/(3 + 5r_L))$;

(3) When $C \geq ((1 + r_L)/2)$, we find $Q^* = 0$

C. Proof of Corollary 1

(1) When $0 < C \leq ((1 + r_L)/2)$, the optimal quality grading r^* of fresh food raises with the improvement of the lowest quality r_L

(i) When $0 < C < ((1 - r_L)/8)$, we obtain $r^* = \delta$, that δ should satisfy the following conditions: $\{(1 - \delta)^3 - 4C(1 - r_L)(1 - \delta) + 8C^2(1 - r_L) = 0 r_L < \delta < 1 - 4C$. Due to $(1 - \delta)^3 = 4C(1 - r_L)(1 - \delta) - 8C^2(1 - r_L) > 0$, $3(1 - \delta)^3 - 4C(1 - r_L)(1 - \delta) = 8C(1 - r_L)(1 - \delta - C)$, we find $3(1 - \delta)^2 - 4C(1 - r_L) > 0$. And due to $[3(1 - \delta)^2 - 4C(1 - r_L)](\partial\delta/\partial r_L) = 4C(1 - \delta) - 8C^2 > 0$, we obtain $(\partial\delta/\partial r_L) > 0$.

(ii) When $((1 - r_L)/8) < C \leq ((1 + r_L)/2)$, the retailer's optimal quality rating standard and purchase quantity are, respectively, $r^* = ((1 + r_L)/2), Q^* = ((2D(1 - 2C + r_L))/(3 + 5r_L))$, and $(\partial r^*/\partial r_L) = (1/2) > 0$.

(2) When $0 < C < ((1 - r_L)/8)$, the optimal quality grading standard of fresh food decreases with the increase of the unit cost. And when $((1 - r_L)/8) < C \leq ((1 + r_L)/2)$, the optimal quality grading standard remains unchanged.

When $0 < C < ((1 - r_L)/8)$, according to the proof of the above, we can obtain that $1 - \delta > 2C$ and $3(1 - \delta)^2 - 4C(1 - r_L) > 0$, and since $0 < C < ((1 - r_L)/8)$, $\delta > r_L$, $(1 - \delta)^3 - 8C^2(1 - r_L) = 4C(1 - r_L)[(1 - \delta) - 4C]$, and $(1 - \delta)^3 > (1 - r_L)^3$, $0 < 8C^2(1 - r_L) < ((1 - r_L)^3/8)$, and we get $(1 - \delta) > 4C$. And due to $[4C(1 - r_L) - 3(1 - \delta)^2](\partial\delta/\partial C) = 4(1 - r_L)(1 - \delta - 4C)$, $3(1 - \delta)^2 - 4C(1 - r_L) > 0$, and $(1 - \delta) > 4C$, we get $(\partial\delta/\partial C) < 0$.

And when $((1 - r_L)/8) < C \leq ((1 + r_L)/2)$, the optimal quality grading standard remains unchanged. It can be easily obtained in Proposition 2.

D. Proof of Corollary 2

According to Proposition 2, when $((1 - r_L)/8) < C < ((1 + r_L)/2)$, the retailer's profit is $\Pi^* = ((D(1 - 2C + r_L)^2)/(6 + 10r_L))$. The first derivative of the profit function with respect to r_L and C are $(\partial\Pi^*/\partial r_L) = (((1 - 2C + r_L)(1 + 5r_L + 10C)D)/(2(3 + 5r_L)^2)) > 0$ and $(\partial\Pi^*/\partial C) = ((-4D(1 - 2C + r_L))/(6 + 10r_L)) < 0$, so that the view is true in Corollary 2.

E. Proof of Corollary 3

(1) According to Appendix 3, we can get $3(1 - \delta)^2 - 4C(1 - r_L) > 0$, $(1 - \delta) > 4C$. Respect to $(\partial\delta/\partial C) = ((4(1 - r_L)[(1 - \delta) - 4C])/(4(1 - r_L)C - 3(1 - \delta)^2)) < 0$, and we get $(\partial Q^*/\partial C) = ((-[C(\partial\delta/\partial C) + (1 - \delta)]D)/8C^2) = (((1 - \delta)^3 D)/(8C^2[4(1 - r_L)C - 3(1 - \delta)^2])) < 0$. When $((1 - r_L)/8) < C < ((1 + r_L)/2)$ and $Q^* = ((2D(1 - 2C + r_L))/(3 + 5r_L))$, we obtain $(\partial Q^*/\partial C) = ((-4D)/(3 + 5r_L)) < 0$. And when $C \geq ((1 + r_L)/2)$, the optimal purchase quantity $Q^* = 0$.

(2) (i) When $0 < C \leq ((1 - r_L)/8)$, we get that $3(1 - \delta)^2 - 4C(1 - r_L) > 0$, $(1 - \delta) > 4C$, $(\partial\delta/\partial r_L) > 0$, and $(\partial Q^*/\partial r_L) = ((-(\partial\delta/\partial r_L)D)/8C)$; as a result, $(\partial Q^*/\partial r_L) < 0$. (ii) When $((1 - r_L)/8) < C < ((1 + r_L)/2)$, the optimal purchase quantity is

$Q^* = ((2D(1-2C+r_L))/(3+5r_L))$, and $(\partial Q^*/\partial r_L) = ((4D(5C-1))/(3+5r_L)^2)$. Hence, when $(1/5) < C < ((1+r_L)/2)$, the optimal purchase quantity is a monotonically decreasing function of the lowest quality level.

(3) When $(1/5) < C < ((1+r_L)/2)$, we get $(\partial Q^*/\partial r_L) > 0$. The optimal purchase quantity increases with the improvement of the lowest quality level.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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