Automatic Pricing and Replenishment Decision-Making for Vegetable Commodities Based on Seasonal Index Prediction Models

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Abstract. This study provides an in-depth analysis of the relationship between sales, pricing, and product categories to construct a predictive model designed to optimize replenishment decisions and maximize superstore profits. The study begins with data preprocessing, integrating data coded according to individual products, on which the model is built and solved. In the first part, descriptive statistical analysis and visualization revealed that the sales volume of each category showed a cluster-like distribution, which was affected by seasonal variations. Based on the time series smoothness test, it is initially judged that each individual product is a smooth series, and the smoothness of the series is verified by ADF test. In the second part, the correlation coefficients of the sales volume of each category and single product were calculated by using Spearman correlation analysis, and the results were presented through heat maps, which revealed the strong correlation between different categories. For the relational equation between total sales volume and cost-plus pricing, an autoregressive and least squares model was developed, with cost-plus pricing as the dependent variable and total sales volume as the independent variable. For the seasonal index prediction model, the total daily replenishment and pricing at future dates were predicted by calculating the seasonal index. The results show that the replenishment volume of flowers and leaves fluctuates greatly, and it is recommended that pricing and replenishment volume be adjusted in a timely manner according to the actual sales situation; cauliflower, aquatic roots and tubers, and eggplant are relatively stable, and they should be adjusted moderately according to the market demand; and chili peppers and edibles are on a downward trend, and it is recommended that replenishment volume be reduced in order to avoid the inventory backlog.

Keywords: Time series smoothness test, Spearman correlation analysis, Autoregression, least square method.

1. Introduction

With the increasing demand for food safety and quality, fresh produce superstores have gained widespread popularity among consumers. However, fresh and high-quality vegetable commodities are highly susceptible to storage conditions and length of time, and most varieties are perishable, requiring a reasonable replenishment plan and pricing strategy.

Based on the sales situation and supply and demand analysis of the vegetable category, the superstore needs to make good replenishment decisions before the purchase transaction. At the same time, according to the purchase cost of various types of vegetables using cost-plus pricing method for pricing decisions, the transportation loss and appearance of damaged goods for discount sales. Merchants need to consider both the demand and supply sides of vegetable sales. On the demand side, consider the correlation between vegetable sales volume and time, and make forecasts and adjustments according to seasonal changes and special festivals; on the supply side, make full use of the vegetable varieties available during the productive season, and choose a reasonable sales mix. Through rational sales strategies and sales combinations, merchants can satisfy consumer demand, improve sales performance, and achieve good results within a limited sales space.

This study needs to address the following questions:

(1) To establish a mathematical model of the distribution law situation and interrelationship of the sales volume of each category and single product of vegetables, to visualize the obtained data, and to find the correlation relationship among them.

(2) In order to maximize the profitability of the superstore, it is necessary to analyze the relationship between the total sales volume of each category of vegetables and the cost-plus pricing, and to provide the total replenishment volume and pricing strategy of vegetables for the coming week (July 1-7, 2023).

2. Materials and Methods/Research Methods

2.1. Data Acquisition and Preprocessing

Through the data research, the data related to sales volume, sales unit price, wholesale price and other relevant data of vegetable category were collected and obtained. Due to the huge amount of data, it is necessary to pre-process the data first, remove the outliers, and integrate the given data into a daily summary table of sales volume of each commodity, a daily summary table of sales volume of each commodity, and a daily summary table of sales unit price of each commodity, and the data processing flow of this study is shown in Figure 1.

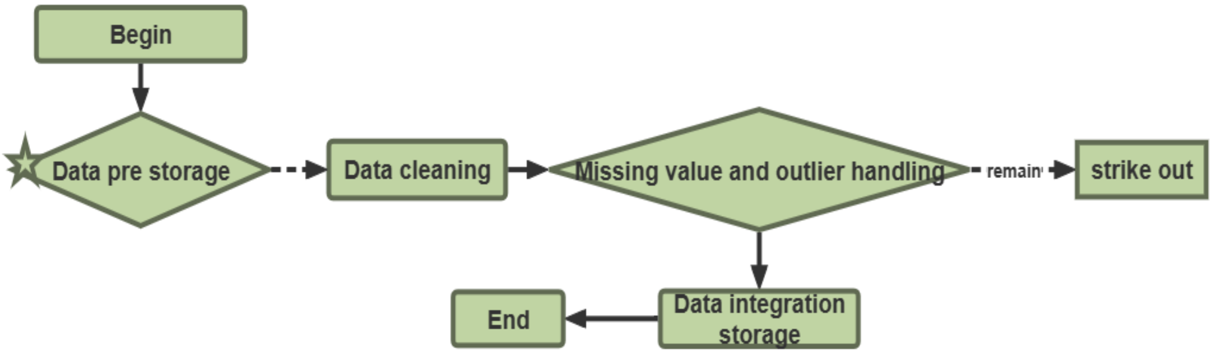


Figure 1. Flow chart of data preprocessing

The research got the sales flow details and wholesale price and other related data of each commodity in the superstore in the past 3 years, due to the large amount of data, it is necessary to carry out certain pre-processing of the given data to prevent the existence of erroneous data in it, which will make the calculation of the results have an impact on the results leading to an error. First of all, the data given are associated using single product coding, and the given data are found to have no missing values through data cleaning. Based on the visualization method, it was observed that there were discrete points that were significantly different from the other observations, i.e., 160kg of fresh rice dumpling leaves were sold on June 9, 2022, and it was determined that the Dragon Boat Festival of 2022 was on June 3 through the calendar access, and the sale of this item was after the Dragon Boat Festival, so we defined this data as an outlier and deleted it. Then, based on the data processing found that the same date the same category of goods in different periods of time there are multiple sales, so the data will be processed in the processing of the day of the sales of each commodity to sum up the day of the sales of the day, the day did not sell the various commodities with 0 to fill in, summarized into a new table, that is, the daily sales of each commodity summary table. At the same time, the sales of each product on the day to sum (sales = sales × unit price), to obtain the daily sales of each product summary table. As the vegetable categories will cause price fluctuations due to changes in supply and demand, that is, the unit price of sales will change with the change of different dates, assuming that the unit price of commodities fixed for a certain date remains unchanged, we take the average of the unit price of sales of each commodity on the day to get the daily summary table of unit price of sales of each commodity. Finally, to complete the data sorting and elimination, the later modeling and solving are built on the basis of this data preprocessing.

2.2. Introduction to the methodology (advantages, rationale)

2.2.1 Principles

(1) Firstly, descriptive statistics and visualization analysis were carried out to observe the distribution pattern of sales volume of each category of vegetables in order to observe its distribution characteristics and patterns. Secondly, the distribution pattern of sales volume of vegetable individual items is tested for the smoothness of time series, and the line graph, autocorrelation graph and partial autocorrelation graph of time series of individual items are plotted by Python to preliminarily determine its smoothness, and the smoothness is verified by ADF test. Finally, the interrelationships between the sales volume of each category of vegetables and the interrelationships between individual products were analyzed separately, and a model was established based on Spearman correlation analysis to calculate the correlation coefficients of each category and individual product, and the interrelationships between them were determined by the depth of the color of the heat map and the size of the correlation coefficients.

(2) First use autoregression and least squares to get the relational equation between them and analyze the relationship between total sales volume of each vegetable category and cost-plus pricing according to the size of the correlation coefficient for their relationship. Then, on the basis of maximizing the superstore's revenue, the total daily replenishment and pricing from July 1 to July 7, 2023, are predicted, and the corresponding stocking and selling strategies are proposed. In this paper, a seasonal index forecasting model is used to first calculate the seasonal coefficients and then make forecasts.

2.2.2 Advantages

(1) The time series smoothness test model developed in this study for the problem can well reveal the time trend and seasonal variation.

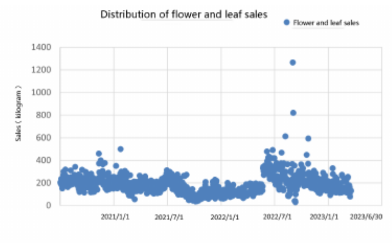
(2) The autoregression and least squares method used in this study for the problem can provide a direct explanation about the relationship of the variables. The regression coefficients and intercept terms can explain the numerical relationship between the variables and help us to understand the influence mechanism between total sales and cost plus; (3) This study applies autoregression and least squares to the problem, which can provide a direct explanation of the relationship between the variables.

(3) The seasonal index forecasting model used in this study to address the problem is able to differentiate and forecast different categories to meet their different demand characteristics.

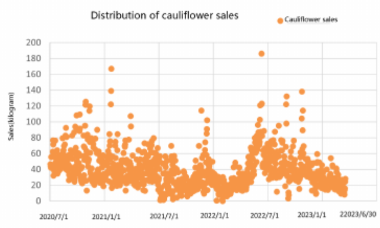
3. Modeling and solving the distribution pattern and correlation relationship of vegetable commodities

3.1. Modeling and solving based on descriptive statistical analysis

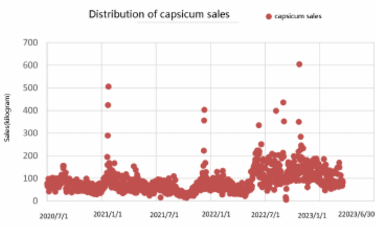
In this paper, based on the daily summary table of sales volume of each commodity obtained after the above data preprocessing, the distribution pattern is analyzed by using the scatter plot of sales volume of each category, with the horizontal axis indicating the time and the vertical axis indicating the sales volume of each category of vegetables, as shown in Figure 2:



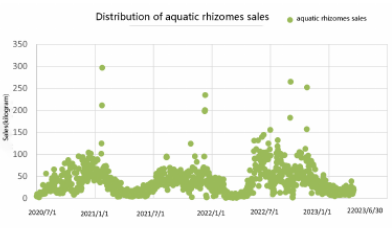
(a) Distribution of flower and leaf sales pattern



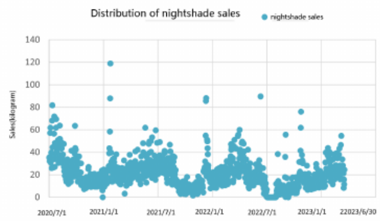
(b) Distribution of cauliflower sales pattern



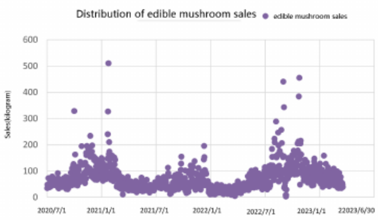
(c) Distribution of capsicum sales pattern



(d) Distribution of aquatic rhizomes sales pattern



(e) Distribution of nightshade sales pattern



(f) Distribution of edible mushroom sales pattern

Figure 2. Scatterplot of distribution pattern of sales volume by category

From the above figure can be obtained from the sales volume distribution pattern of each category as:

(1) **Cluster distribution:** leafy sales volume concentrated in (200,400); cauliflower sales volume concentrated in (15,80); pepper sales volume concentrated in (0,200); aquatic root sales volume concentrated in (0,100); tomato sales volume concentrated in (15,40); edible fungi sales volume concentrated in (0,200); sales volume concentrated in (0,200); sales volume concentrated in (0,200); sales volume concentrated in (0,200); sales volume concentrated in (0,200); sales volume concentrated in (0,200); sales volume concentrated in (15,40); sales volume concentrated in (15,40); sales volume concentrated in (15,40); sales volume concentrated in (15,40) The sales volume of edible fungi was concentrated in (0,200). This indicates that each category shows a cluster-like distribution, that is, the demand for certain categories in a certain period of time shows similar characteristics, forming an obvious agglomeration. This may reflect consumers' preference for certain categories or the special growing environment of certain regions for certain categories.

(2) **Analysis of outliers:** Some scatter points in each category of vegetables deviate from the overall trend, which indicates that there may be some special circumstances. For example, in a particular region or season, the demand for a certain category of vegetables may suddenly increase, resulting in its corresponding scatter points deviating from the overall trend.

(3) **Data dynamics:** The scatterplot demonstrates the changes in the distribution of vegetable category sales over time. By observing the distribution of scatter points at different points in time, it is found that the sales volume of each category has its peaks and valleys in a year, indicating that it is affected by seasonality. The sales of cauliflower and eggplant peaked at certain times of the year, suggesting that they are associated with certain festivals. Sales of aquatic roots and mushrooms show a downward trend during the winter months, suggesting seasonal influences on the availability of this category.

3.2. Modeling and solving based on time series smoothness test [1]

The flowchart of the smoothness test in this study is shown in Figure 3:

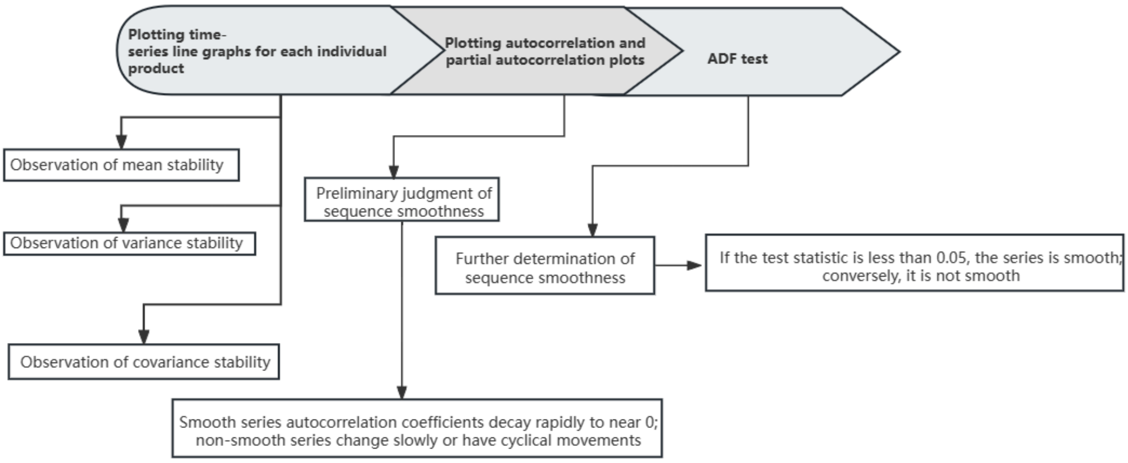


Figure 3. Flow chart of stability test

Based on the data preprocessing, the data are visualized by drawing a line graph of the time series, with time as the horizontal coordinate and sales volume as the vertical coordinate. Analyze the stability of the mean, variance and covariance to determine the stability of the time series. Observe the overall trend of the data in the line graph to see if the data fluctuates around a certain value. If the data fluctuate around a stable mean value, it means that the mean value is relatively stable, indicating that the time series is stable; observe whether the amplitude of the fluctuation of the data in the line graph varies greatly. If the amplitude of the fluctuation is small, that is, the variance is relatively stable, indicating that the time series is smooth; observe whether the frequency or compactness of the fluctuation of the data in different time periods in the line graph varies greatly. If the frequency or compactness of fluctuation is relatively stable, it indicates that the time series is smooth [2].

The line graph of the time series of some individual products in this study is shown in Figure 4:

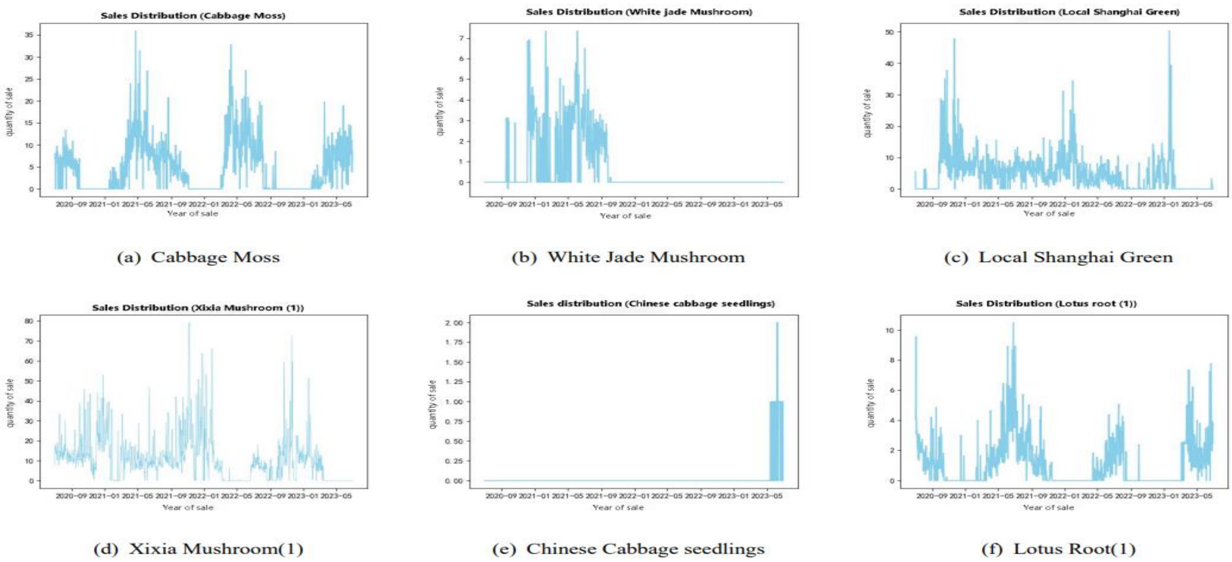
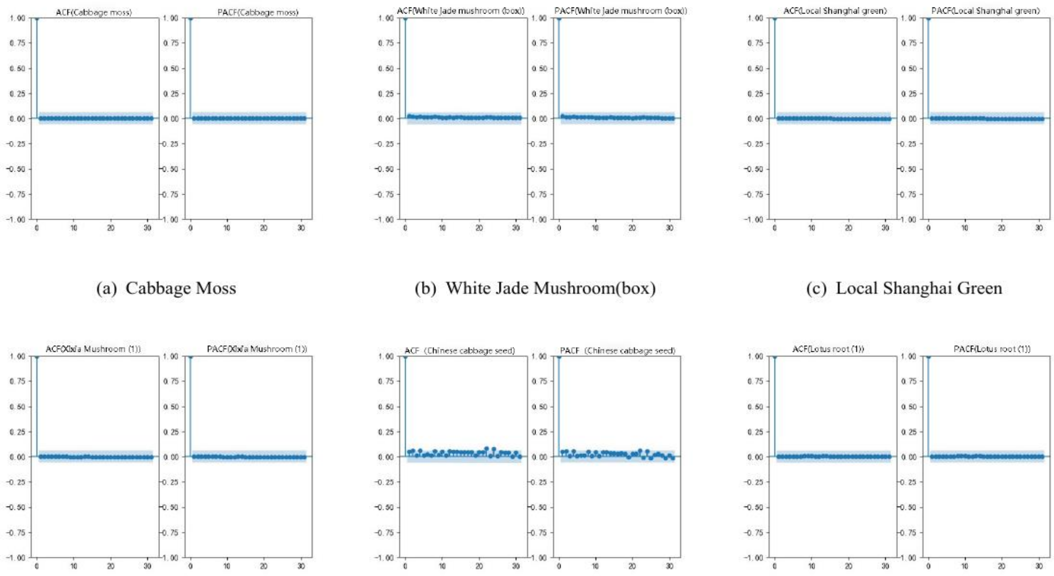


Figure 4. Time-series line graph of selected individual products

Plot the autocorrelation and partial autocorrelation plots of the time series to determine whether the series is stable or not according to the changes of autocorrelation coefficients of different time series. If the time series is stable, the autocorrelation coefficient decreases rapidly to around 0. If the time series is unstable, the autocorrelation coefficient decreases slowly or fluctuates periodically. Meanwhile, the partial autocorrelation plots are used to observe the importance of the lag degree in the time series to the target series.

In this paper, we only show some images of ACF and PACF.



(a) Cabbage Moss (b) White Jade Mushroom(box) (c) Local Shanghai Green

(d) Xixia Mushroom(1) (e) Chinese cabbage seedling (f) Lotus Root(1)

Figure 5. Autocorrelation and partial autocorrelation plots for selected individual items

From the image analysis (Figure 5), we can get the distribution law of the sales volume of individual products:

(1) The autocorrelation coefficient of the 251 individual items of the Vegetables category decreases rapidly to around 0, which is a smooth series, indicating that the sales volume of each individual item is relatively stable in terms of statistical characteristics. However, the time-series line graphs show a tendency to fluctuate in the line graphs, which is affected by the seasonality or cyclicity, which indicates that the data have trend changes and stable correlation at the same time. This is due to the fact that the effect of the trend is smoothed out at different lag time steps, or due to the seasonal or cyclical factors of some individual products.

(2)Through the time series of individual items, it can be found that the sales volume of individual items such as cabbage moss, local Shanghai green, and Chinese cabbage seedlings are higher in spring; the sales volume of individual items such as bell peppers is higher in summer; the sales volume of individual items such as Chinese cabbage in Dongmenmen, Xixia mushrooms, and Chinese cabbage seedlings is higher in fall; and the sales volume of individual items such as iceplant, Xixia mushrooms, and lotus roots is higher in winter, which means that different individual items are affected by the seasonality of different products.

In order to further determine the smoothness of the time series, the ADF test is used to determine whether the original hypothesis is rejected according to the test statistic and the corresponding critical value (P value). If the P-value is less than 0.05, the original hypothesis is rejected, indicating that the series is smooth.

3.3. Establishment and solution of Spearman's correlation-based analytical models [3]

In this paper, based on the summary table of daily sales volume of each product obtained from data preprocessing and the product information of six vegetable categories given in Annex 1, the daily sales volume of individual products belonging to leafy flowers, cauliflower, pepper, aquatic roots and tubers, eggplant, and edible mushrooms are summed up respectively. Since the distribution pattern of each category shows a non-linear relationship, the correlation coefficient is calculated by using Spearman correlation analysis [4], and the interrelationship between categories is reflected by heat map. Spearman correlation coefficient is calculated as:

$$\rho = \frac{\frac{1}{n}\sum_{i=1}^{n}\left(R(x_i)-\overline{R(x)}\right)\left((y_i)-\overline{R(y)}\right)}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(R(x_i)-\overline{R(x)}\right)^2\left(\frac{1}{n}\sum_{i=1}^{n}\left(R(y_i)-\overline{R(y)}\right)^2\right.}} \quad (1)$$

Of which:

$R(x_i).R(x_i)$ is the rank of x and y respectively, i.e., the ranking of the sales volume of each category.

$\overline{R(x)}$. $\overline{R(y)}$ are the average rank of x and y respectively.

The heat map of correlation coefficients for each category in this study is shown in Figure 6:

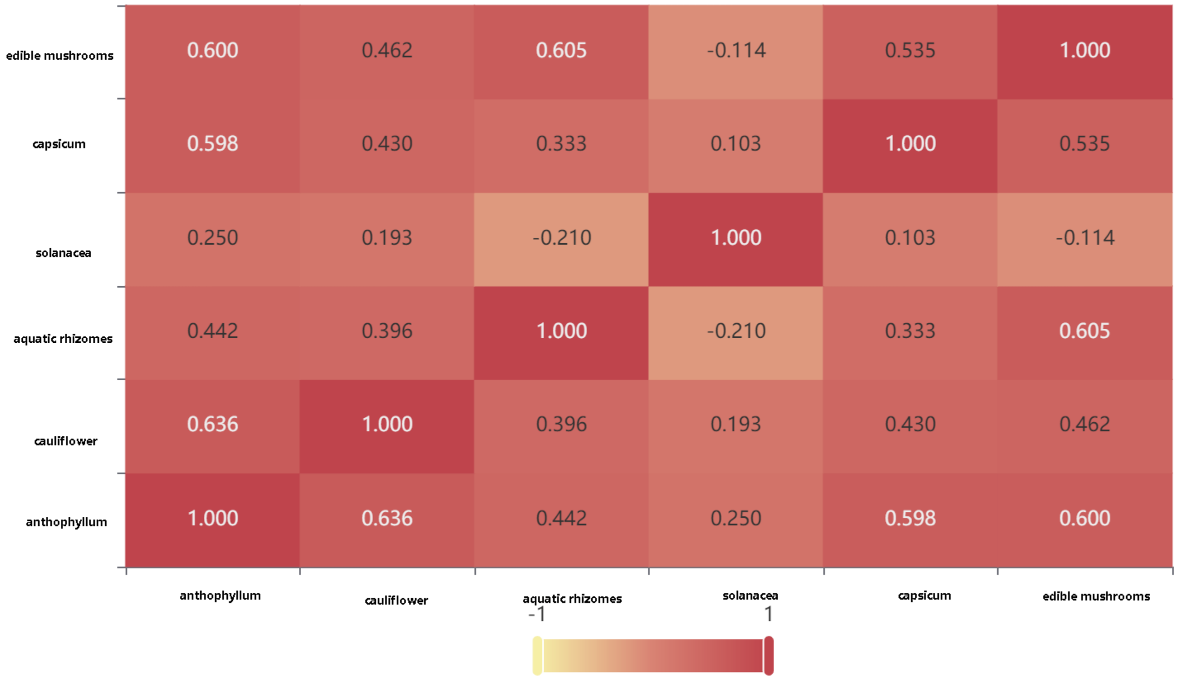


Figure 6. Heat map of correlation coefficients by category

The Spearman correlation coefficient takes values between [-1,1]. Close to 1 means there is a strong positive monotonic relationship, close to -1 means there is a strong negative monotonic relationship, and close to 0 means there is no monotonic relationship. According to the color depth of the heat map to determine the correlation between vegetable categories, the analysis of the above figure shows that the foliar and cauliflower, foliar and edible mushrooms, aquatic rhizomes and edible mushrooms are positive monotonic relationship, which means that the correlation is strong, indicating that when the value of one variable is increased, the value of the other variable is also increased. For example, floribundas and cauliflowers showed the same increasing trend in sales with different time changes. While there is almost no monotonic relationship between cauliflower and eggplant, eggplant and pepper, edible mushrooms and eggplant, indicating that there is no linear relationship between them, and the correlation is weak.

According to the above monotonous distribution pattern, the distribution of monotonous items was nonlinear, so the correlation coefficient was calculated by Spearman correlation analysis, and the correlation coefficient heat map was used to reflect the interrelationships among monotonous items. Since there are 251 kinds of single products, this paper only shows the interrelationship between the first 20 kinds of single products, the specific analysis results are shown, and the heat map of correlation coefficient is shown in Figure 7.

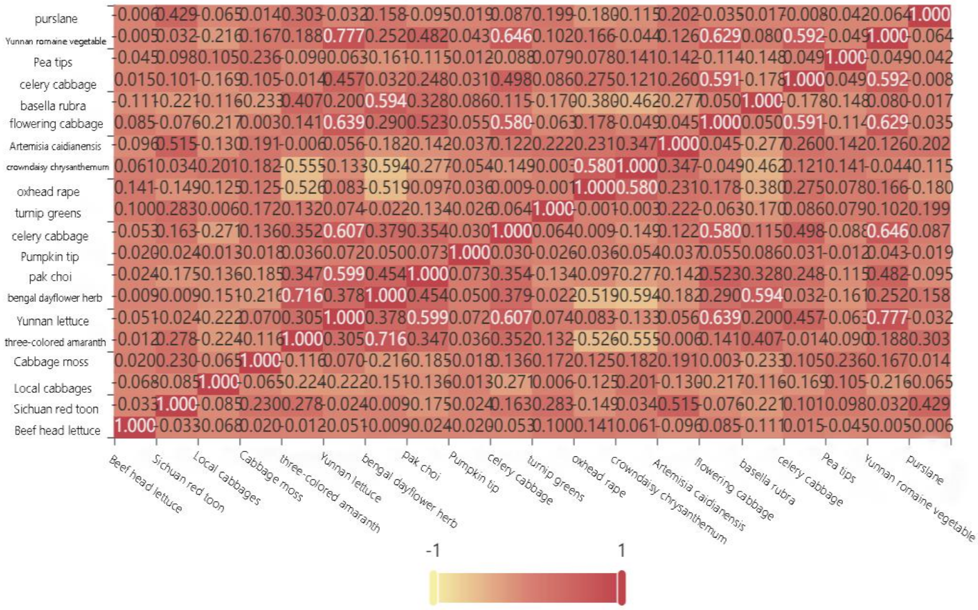


Figure 7. Heat map of correlation coefficients of individual products

As analyzed in Figure 7, amaranth and bamboo leaf lettuce, Yunnan lettuce and radish leaves, Yunnan lettuce and Yunnan oilseed rape, and Shanghaiqing and Yunnan oilseed rape were positive monotonous relationships with strong correlations; amaranth and Chrysanthemum coronarium, bamboo leaf lettuce and Chrysanthemum coronarium, bamboo leaf lettuce and radish leaves were negative monotonous relationships with relatively strong correlations; and there were no monotonous relationships between oxalic acid lettuce and amaranth, Amaranthus and cabbage, and Amaranthus and bamboo leaf lettuce with relatively weak correlations.

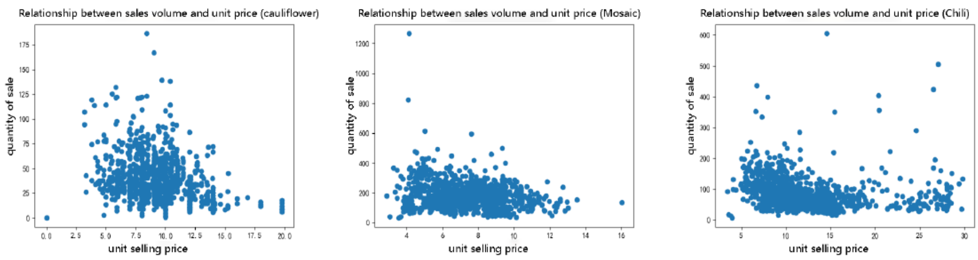
4. Modeling and solving the replenishment plan for vegetable commodities

4.1. Autoregressive [5] and Least Squares [6] Based Modeling and Solving

In this paper, on the basis of data preprocessing, the sales volume of each category of vegetables is firstly summed up according to the date, and then the average unit price of the category on the same day is calculated, and an autoregressive and least square [7] model is established, with the sales volume of each category as the dependent variable and the sales unit price as the independent variable. Analyze the relationship between the total sales volume of each category and cost-plus pricing, which is based on the production cost of the product, and the sales price covers the cost and earns a certain profit. The calculated relationship shows how the sales volume varies with the change in unit price; a positive coefficient indicates that the sales volume of the category increases with the increase in unit price; a negative coefficient indicates that the sales volume of the category decreases with the increase in unit price. The relationship between total sales volume and cost-plus pricing for each category of vegetables is shown in Table 1:

Table.1. Relationship between total sales and cost-plus pricing by category

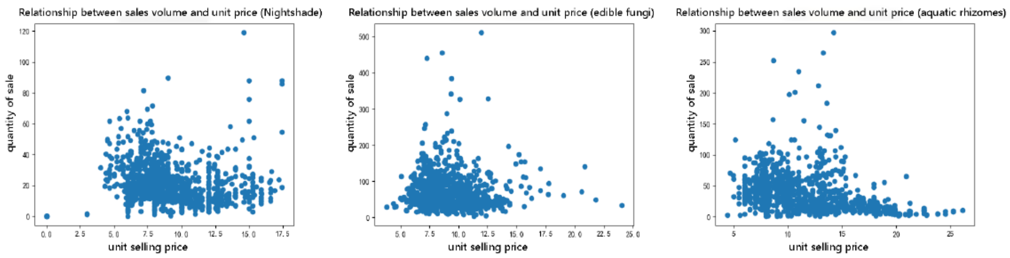
vegetable category	Total sales and cost-plus pricing equation
Mosaic	$y=-3.5909x+0.5883\beta+101.3688$
Cauliflower	$y=-1.0260x+0.6251\beta+23.974$
Aquatic rhizomes	$y=-0.7733x+0.6474\beta+22.078$
Nightshade	$y=0.058x+0.6982\beta+5.7078$
Chili	$y=-0.5695x+0.6797\beta+34.1715$
Edible fungi	$y=-0.7119x+0.6596\beta+30.4132$



(a) Relationship between sales volume and unit price(Cauliflower)

(b) Relationship between sales volume and unit price(Mosaic)

(c) Relationship between sales volume and unit price(Chili)



(d) Relationship between sales volume and unit price(Nightshade)

(e) Relationship between sales volume and unit price(Edible fungi)

(f) Relationship between sales volume and unit price(aquatic rhizomes)

Figure 8. Relationship between sales volume and unit price by category

According to the relationship equation and image analysis (Figure 8), the relationship between total sales volume and cost-plus pricing for each category is [8]:

The coefficients of foliage, cauliflower, aquatic roots and tubers, chili peppers and edible mushrooms are negative, and the total sales volume is negatively correlated with the cost-plus pricing, which means that the sales volume of these items decreases with the increase of the unit price. The coefficients for foliage and flowers are larger, indicating that the sales volume of foliage and flowers is more sensitive to changes in unit prices than other categories.

The total sales volume of Solanum category is positively correlated with cost plus pricing, i.e., when the total sales volume increases, the pricing increases. However, the coefficient is 0.058, indicating that the degree of change is relatively small, probably because eggplant is subject to seasonal influences, and the price will increase when demand exceeds supply.

4.2. Establishment and Solution of Seasonal Index Based Prediction Models [9]

In this paper, a seasonal index forecasting model is used to predict the total daily replenishment and pricing of each vegetable category from July 1-7, 2023, and to provide strategies to maximize the revenue of supermarkets. The total amount of replenishment needs to take into account the effect of the wastage rate of each product in Annex 4, which is calculated by the sales volume / (1 - wastage rate).

Calculate the seasonal index [10]: First, group the sales volume and pricing data of each category from July 1, 2020, to June 30, 2023, according to the weekly time period as given in the Annex, and calculate the average replenishment volume and pricing in each time period. Next, the seasonal index is calculated for each time period as the ratio of the average of that time period to the average of the entire data set, using the formula: Seasonal Index = average of one week's data/average of all weeks in a three-year period

Forecasting with seasonal indices: The seasonal indices for the last three years are used to forecast the week ahead. The historical seasonal indices for the coming week are weighted and summed with the seasonal indices for the last three years to obtain the forecast. The formula is:

$$H_i = (w_1 \times s_{i1}) + (w_2 \times s_{i2}) + (w_3 \times s_{i3}) \quad (2)$$

The total daily replenishment and pricing forecasts for each category for the coming week are shown in Table 2:

Table.2. Forecast of total daily replenishment for each vegetable category in the coming week

Date	Mosaic	Cauliflower	Aquatic rhizomes	Nightshade	Chili	Edible fungi
2023-07-01	229.660	30.999	16.173	28.100	82.632	78.717
2023-07-02	208.075	30.549	14.446	30.679	78.317	78.342
2023-07-03	138.692	27.937	11.182	24.259	64.993	51.259
2023-07-04	132.879	28.556	12.122	22.389	65.756	47.937
2023-07-05	132.886	28.540	12.445	22.333	68.068	58.241
2023-07-06	123.171	28.218	12.338	22.288	65.071	52.375
2023-07-07	157.125	28.157	14.907	23.527	70.773	60.743

Based on the data in the above table, in order to get the maximum benefit, the analysis is done to get the total daily replenishment strategy for each category in the coming week (Figure 9 and Table 3):

(1) Foliage: According to the data, the total daily replenishment amount of foliage category has a big fluctuation in the coming week. Therefore, it is necessary to monitor changes in market demand in a timely manner and flexibly adjust the replenishment amount according to the actual sales situation.

(2) Cauliflower and eggplant: Forecast data show that the total daily replenishment of cauliflower and eggplant is relatively stable. It is recommended that a fixed amount of replenishment be carried out according to historical sales data and demand to ensure sufficient stock.

(3) Aquatic Roots and Tubers, Edible Mushrooms and Chili Peppers: Forecast data shows a decrease in total daily replenishment in the coming week. It is recommended that adjustments be made according to sales data and market demand, which may appropriately reduce the amount of replenishment, and pay close attention to changes in sales to avoid backlogs in inventory.

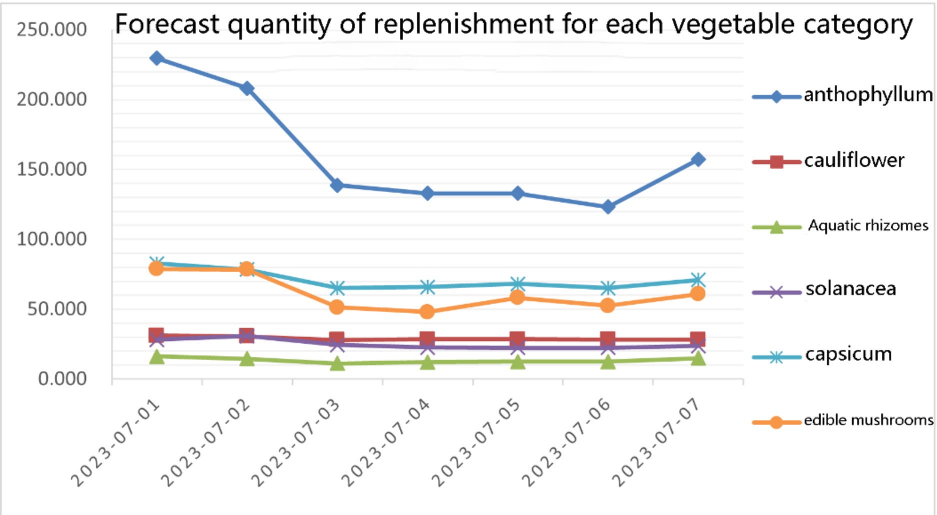


Figure 9. Forecast of Total Replenishment by Vegetable Category

Table.3. Pricing Forecast by Vegetable Category for the Week Ahead

Date	Mosaic	Cauliflower	Aquatic rhizomes	Nightshade	Chili	Edible fungi
2023-07-01	6.04	6.05	14.35	7.80	8.06	6.47
2023-07-02	6.50	5.67	13.96	7.73	8.00	6.64
2023-07-03	6.16	5.65	14.72	7.80	7.57	6.80
2023-07-04	6.23	5.77	15.37	7.80	8.39	6.86
2023-07-05	5.22	5.67	14.27	7.30	8.03	6.74
2023-07-06	5.76	6.38	13.41	7.64	8.27	6.81
2023-07-07	6.49	6.49	14.67	7.73	8.06	6.98

Based on the data in the table above, the pricing strategy for each category for the coming week is analyzed in order to maximize revenue (Figure 10):

(1) Foliage and Cauliflower: According to the forecast data, the pricing of the Foliage category will change relatively little in the coming week, with an overall upward trend. It is recommended that pricing be adjusted in a timely manner and that a relatively stable pricing strategy be adopted, but close attention should be paid to market competition and consumer demand to maintain competitiveness.

(2) Aquatic Roots & Tubers: The data shows that pricing in the Aquatic Roots & Tubers category is relatively high, with little fluctuation in the forecast. It is recommended that pricing take into account the uniqueness of the category and market competition, while paying attention to costs and profits to ensure reasonable pricing.

(3) Eggplant, Pepper and Edible Mushrooms: Forecasts show that pricing for eggplant and pepper is relatively stable, with little change in the coming week. It is recommended that pricing be based on market demand and competition, while paying attention to product quality and profit margins.

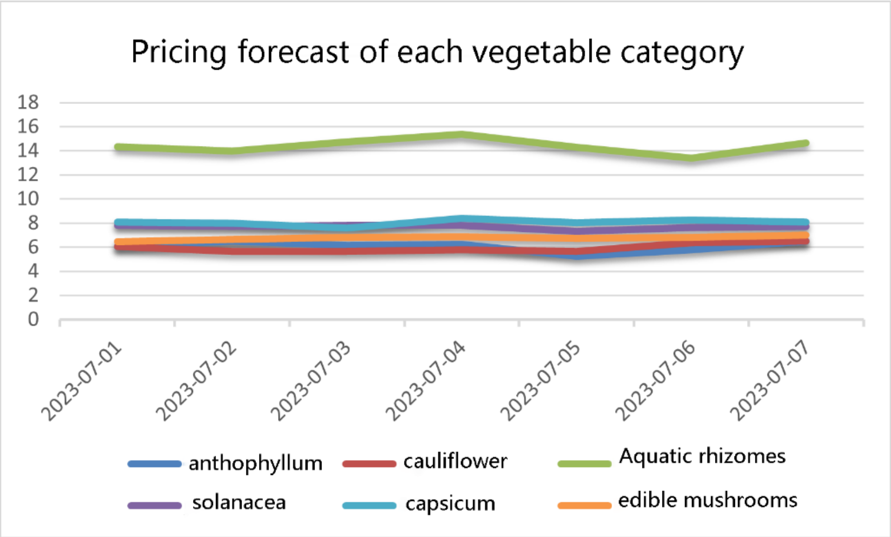


Figure 10. Pricing Forecast by Vegetable Category

5. Conclusion

This study provides a forecasting model for superstores to optimize replenishment decisions and maximize profits. Through an in-depth analysis of the relationship between sales, pricing, and product categories, the study reveals the cluster distribution of the sales volume of each category, which is affected by seasonal variations, and provides corresponding adjustment suggestions for different product categories. An autoregressive and least squares model was developed to gain insight into the relationship between total sales volume and cost-plus pricing. By calculating seasonal indices, daily replenishment totals and pricing are predicted for future dates. The results show that there are fluctuating differences between different product categories. The replenishment volume of flowers and leaves fluctuates greatly, and it is recommended that pricing and replenishment volume be adjusted in a timely manner according to the actual sales situation; cauliflower, aquatic roots and tubers, and eggplant are relatively stable, and it is recommended that they be adjusted moderately according to the market demand; chili peppers and edibles are on a downward trend, and it is recommended that replenishment volume be reduced in order to avoid the inventory backlog. Supermarkets need to adjust pricing and replenishment according to the actual sales situation, so as to better formulate business strategies in a competitive market, better adapt to consumer demand, and maximize operating profits.

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