A Study on Autonomous Pricing and Replenishment Decision of Vegetable Commodities Based on Gray Time Series Forecasting and Single-Objective Planning Models

Weilin Liu *, Bowen Wu

School of Electrical and Electronic Engineering, Shandong University of Technology, Zibo, China, 255000

* Corresponding author: 19862421258@139.com

Abstract. Automated pricing and replenishment of vegetable items is one of the hot issues of the new era. In order to make replenishment decisions on the day's vegetable goods for superstores, this paper first constructs a nonlinear regression model to fit the function of vegetable category pricing and daily sales volume, and finds that the two have a negative correlation; Second, this paper predicts the cost of each category of vegetables for the coming week by building a gray time series prediction model; Finally, this paper takes the pricing of different categories on different dates as the decision variable, maximizes the revenue of the superstore as the objective function, establishes a single-objective planning model with the maximum capacity of the category and other constraints, and determines the optimal daily replenishment and pricing decisions based on the dynamic planning algorithm using the idea of iteration.

Keywords: Gray time series forecasting, single-objective planning, nonlinear regression.

1. Introduction

Automatic pricing and replenishment of vegetable commodities is one of the hot issues in the new era. In the case that the unit price of specific vegetable items and the purchase price are unknown, generally speaking, the supermarket system needs to automatically make the replenishment decision of vegetable commodities for the day according to the historical demand and sales situation. Product replenishment is related to shelf life, quality, etc. Most varieties of vegetables are sold only on the same day and are no longer sold on the next day[1]. In order to reduce the loss rate and maximize profits, supermarkets can sell vegetables at a discount through factors such as the loss rate and quality of individual products. At the same time, whether the market demand is reliable or not can directly affect the automatic replenishment decision and pricing decision of vegetable products. By analyzing the demand trend of each vegetable in different time periods, the accuracy and sensitivity of the automatic system can be improved and the stability of vegetable supply can be carried out.

In order to make same-day replenishment decisions of vegetable commodities for superstores, it was found that Zheng Lü scholars optimized the solution by establishing a batch dynamic model with inventory and supply capacity as constraints, and a heuristic algorithm based on Lagrangian relaxation, which ultimately reduces the cost of replenishment effectively [2]; Based on the in-depth analysis of the multiple factors affecting the fluctuation of vegetable prices, the scholars of Mao Lisha intelligently fit the vegetable data based on Python programming to get the best ARIMA model, so as to intelligently predict the price trend of leafy vegetables, root vegetables, and lycopene vegetables. Finally, the optimization of vegetable supply chain in practical application is studied from the aspects of pricing strategy and production and marketing model. [3]; Huang Hongfu established a dual-channel inventory control and pricing game model considering the perishability of products, and studied the optimal inventory control and optimal pricing decisions of suppliers and retailers at two levels from the perspectives of centralized decision-making and decentralized decision-making, and found that it is conducive to reducing wastage and increasing profits [4].

In this paper, firstly, by non-linear regression based on the data of total daily sales and cost pricing of each vegetable category; secondly, this paper establishes a single-objective planning model by taking the pricing of different categories at different times as the decision variable, maximizing the

revenue of the superstore as the objective function, and taking the maximum capacity of the category and the maximum capacity of the specific category of the superstore as the constraints, and then formulates the decision-making plan for the daily replenishment and pricing of the coming week based on the above fitted function expressions.

2. Autonomous Pricing and Replenishment Modeling and Solving

2.1. Analysis of ideas

The specific idea map is shown in Figure 1:

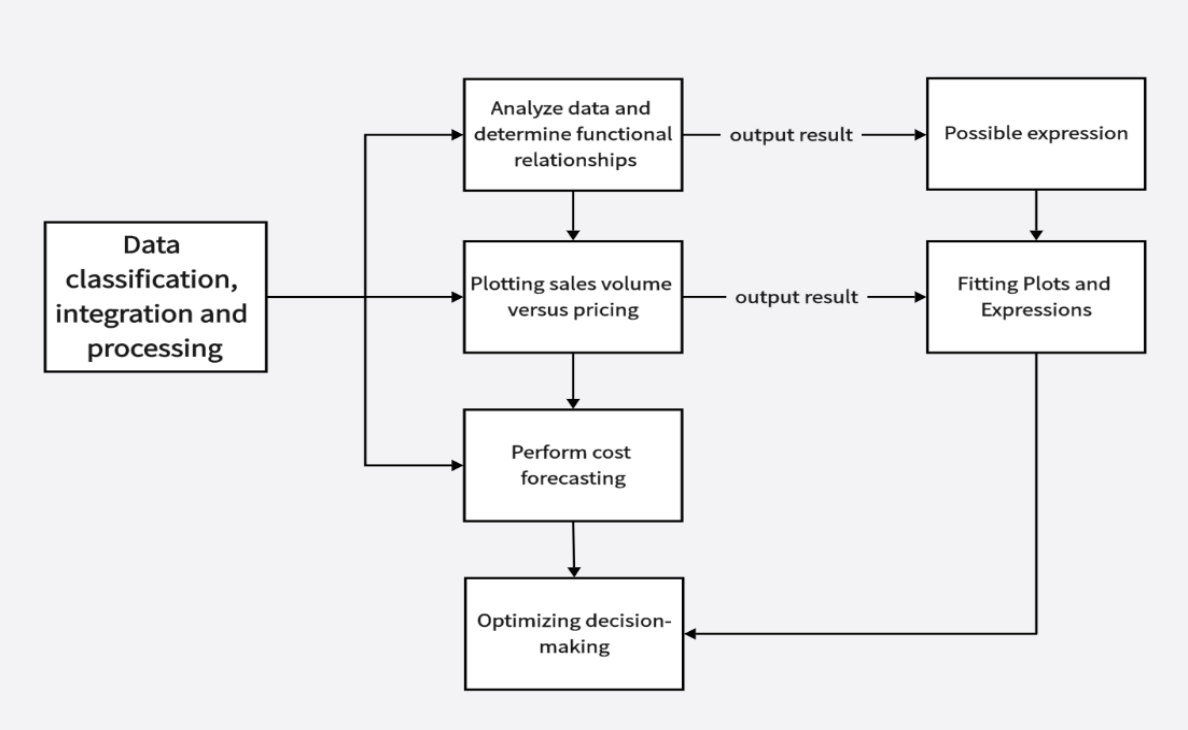


Figure 1. Idea analysis diagram

2.2. Nonlinear regression

2.2.1. Separate analysis for each type of vegetable

Regression analysis based on the competition data reveals that the total sales volume of each vegetable category does not conform to a linear relationship with cost-plus pricing, so this paper performs a nonlinear regression [5]. In this paper, the total daily sales volume of each type of vegetables is selected as the total sales volume, and the expression of the selected function by constant fitting is

$$f(x) = a * x^b + c \tag{1}$$

Included among these, x Indicates pricing, $f(x)$ Indicates total daily sales, a、b、c Indicates a constant.

In this paper, regression analysis was performed to obtain the images shown in Figure 2, 3, 4:

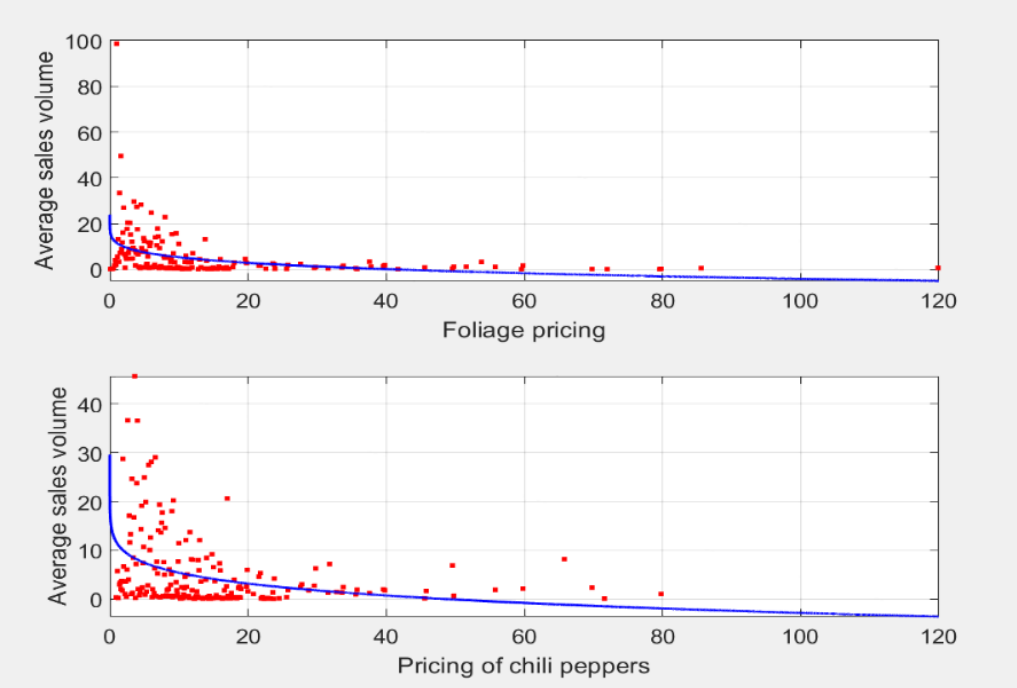
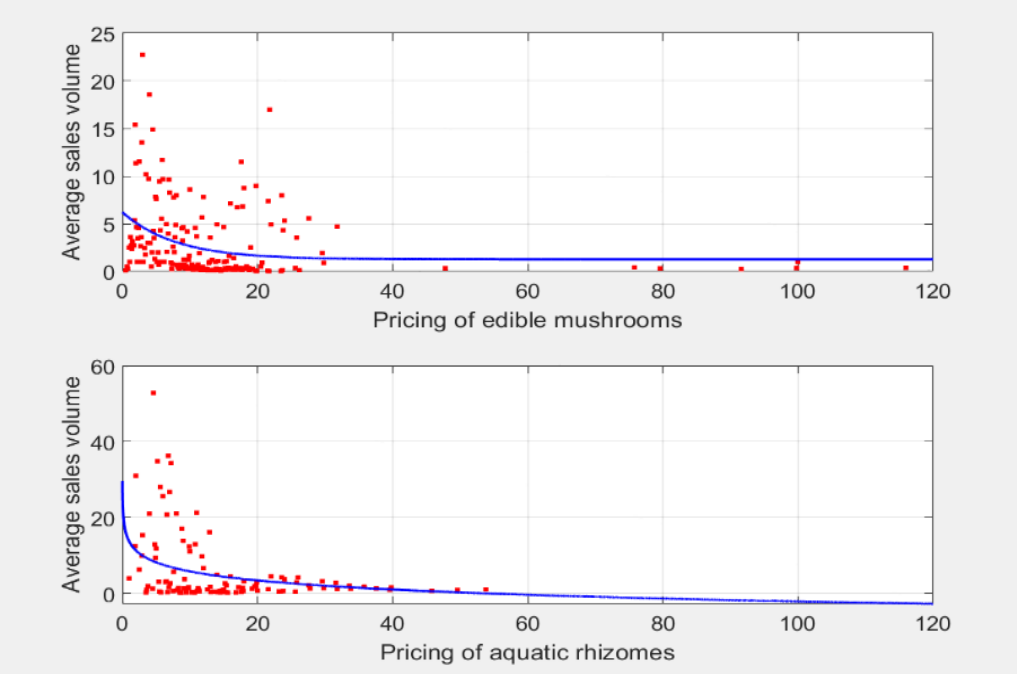


Figure 2. Flowering foliage and chili peppers



Figures 3. Edible mushrooms and aquatic rhizomes

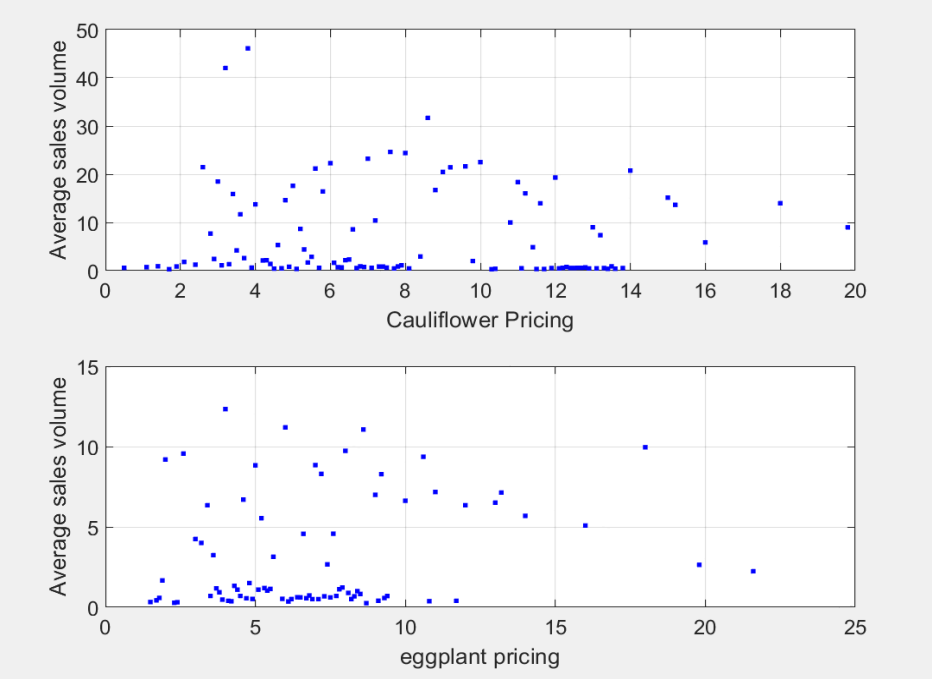


Figure 4. Cauliflower and Solanum

The above results indicate that for cauliflower, chili, edibles, and aquatic roots and tubers, there is an overall negative correlation between total sales and cost-plus pricing for each vegetable category. For cauliflower and eggplant, there is no regular relationship between total sales and pricing, and this result may be due to the fact that this vegetable category is more affected by other factors than the price factor.

2.2.2. Overall analysis of various types of vegetables

The data for each type of vegetable was taken as a whole set and the results of the regression analysis are shown in Figure 5:

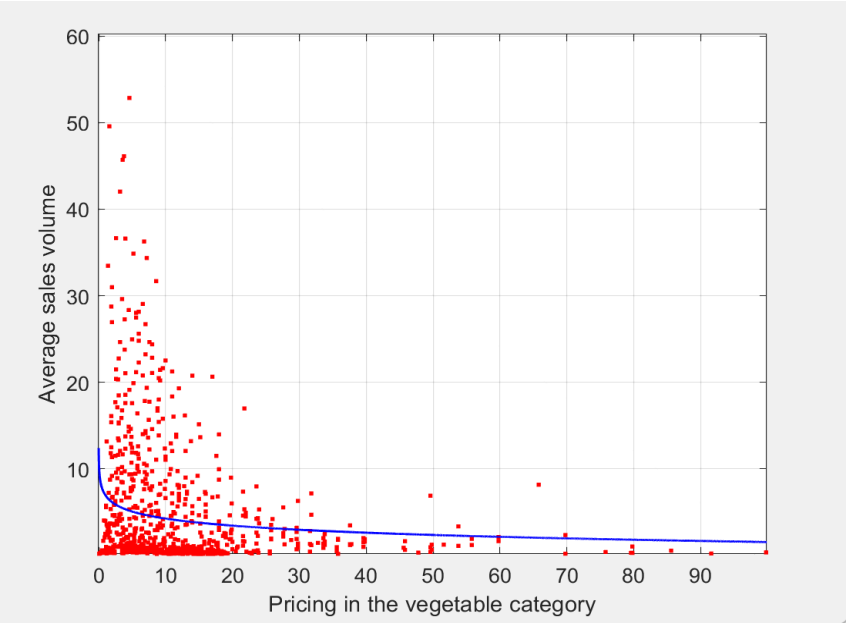


Figure 5. Overall regression analysis of the vegetable category

The regression function expression is

$$f(x) = 2015 \cdot x^{-0.0009369} - 2006 \tag{2}$$

It can be seen that the overall negative correlation between total sales and cost-plus pricing for each vegetable category is not significant. The overall trend shows high similarity with the four categories of foliage, chili, edibles, and aquatic roots and tubers, and is not significantly affected by cauliflower and eggplant, so the overall results can be used to express the relationship between each vegetable category and pricing.

2.3. Cost-price forecasting based on gray time series forecasting model

In this paper, based on the data from 2020 to 2022, the cost from July 1 to 7 of each year is selected for forecasting, and due to the small total amount of dataset, we can try to use the gray time series forecasting model to forecast the cost and price.

Step 1: Grade ratio test

Forecasting based on the gray time series requires a rank test of the time series, which is given as

$$\lambda^{(0)} = (\omega^{(0)}(1), ..., \omega^{(0)}(7)) \tag{3}$$

$$\lambda(k) = \frac{\omega^{(0)}{}_{k-1}}{\omega^{(0)}{}_{k}} \tag{4}$$

Included among these, ω Denote the cost time series, λ Indicates a grade ratio.

If the rank ratio test shows that it passes, it means that the sequence can be predicted by the model; on the contrary, if the rank ratio test shows that it does not pass, it can pass the rank ratio test by certain methods, such as the method of "translation transformation"[6].

Step 2: Perform gray time series forecasting

$$p(k) + \alpha \cdot p(1) = \beta \tag{5}$$

Included among these, for existing data sets, $p(1)$ denotes the first cost data point, $p(k)$ denotes the kth cost data points, α、β denotes the parameter to be estimated.

In this paper, the existing data are first processed to generate a new cumulative series, and then a first-order linear differential equation is set up and estimated using the parameters α and β in order to accomplish the prediction of the time series cost values [7].

The resulting cost projections for each type of vegetable from July 1 to July 7 are shown in Table 1:

Table 1. Cost projections

Category/Date	philodendron	capsicum	eggplant	edible mushrooms	cauliflower category	aquatic rootstock
7-1	2.625728	19.54096	7.456228	4.637776	4.869242	13.44506
7-2	2.148565	14.04684	5.98053	3.581176	4.995545	8.523517
7-3	2.658513	14.174	7.238101	3.55661	5.444103	10.41992
7-4	3.362457	14.98191	7.576163	4.680077	6.531103	14.834
7-5	3.34404	17.96653	4.462934	4.26671	6.200532	10.44716
7-6	2.942978	13.23187	4.640184	3.079542	6.284296	7.88529
7-7	3.07776	16.02564	4.494711	3.996325	5.868649	7.838544

In this paper, the above results are visualized and analyzed as shown in Figure 6. It can be seen that the predicted cost of each belongs to a good stability, the predicted cost results can be used in the subsequent process for calculation.

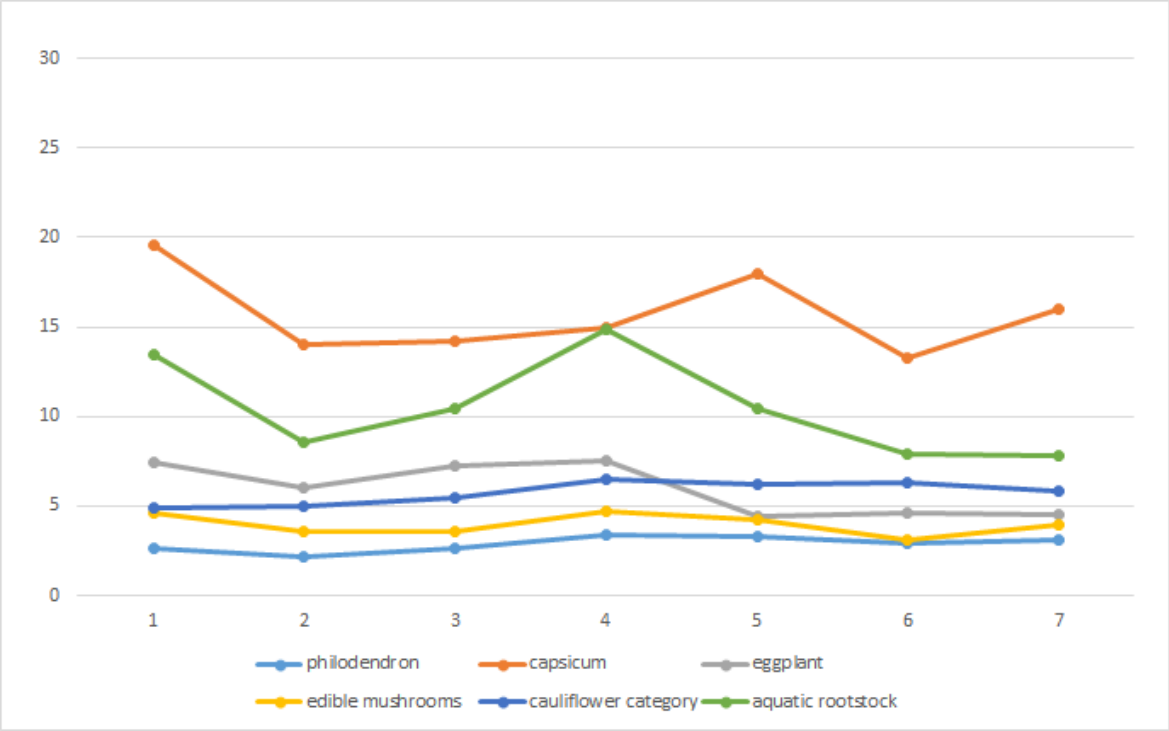


Figure 6. Trends in projected costs by individual product

2.4. Single-objective planning modeling and solving

2.4.1. Determination of decision variables

Decisions on the daily replenishment quantity as well as pricing for the vegetable category are required, therefore, daily pricing is specified as the decision variable

$$x_{ij}(i=1,...,6;\ j=1,...,7) \tag{6}$$

In this paper, we adopt the "cost-plus pricing" method, which is characterized by the relationship between the markup rate and the pricing [8], as follows

$$x_{ij} = (1+w_{ij}) \cdot \mathrm{v}_{ij} \tag{7}$$

Among them, i indicates six different vegetable categories. j indicates dates of July 1st through 7th. w_{ij} indicates the cost-plus rate for vegetables in category i on day j. v_{ij} denotes the cost price of Vegetable Category i on Day j as predicted above.

Based on the expression for the relationship between sales volume and pricing fitted above, we get sales volume

$$y_{ij} = f(x_{ij}) \tag{8}$$

Among them, y_{ij} denotes the sales volume of vegetable items of category i on day j. x_{ij} indicates the pricing of vegetable items in category i on day j.

2.4.2. Determination of the objective function

According to the question, it is required to maximize the profit of the superstore, therefore, this paper sets the objective function as

$$\max \sum_{j=1}^{7} \sum_{i=1}^{6} (x_{ij} - b_{ij}) \cdot y_{ij} \tag{9}$$

Among them, b_{ij} denotes the cost price of a single vegetable item of category i on day j.

2.4.3. Determination of constraints

Restocking is controlled to be equal to sales in order to minimize losses due to unsold vegetables while meeting market demand as much as possible [9].

Based on historical data, the historical maximum daily sales total is taken as the maximum cargo capacity of the vegetable category. The maximum daily sales volume of each vegetable category cannot exceed this maximum cargo capacity. Accordingly, the total cargo capacity constraint is determined as

$$f(x_i) < B_i \tag{10}$$

Among them, $B_i (i = 1,...,6)$ indicates the maximum cargo capacity for vegetable commodities in Category i.

At the same time, take the maximum value of the total daily sales of various types of vegetables in the superstore as the superstore's maximum daily cargo capacity for such vegetables, the replenishment of various types of vegetables cannot exceed the maximum cargo capacity, accordingly determine the cargo capacity constraints for each category as follows

$$\sum_{i=1}^{6} f(x_{ij}) < \mathrm{A} \tag{11}$$

Among them, A denotes the maximum daily capacity of the superstore for vegetables.

In summary, this paper can establish a single-objective planning model [10] as follows

$$\max \sum_{j=1}^{7} \sum_{i=1}^{6} (x_{ij} - b_{ij}) \cdot y_{ij} \tag{12}$$

$$s.t. \begin{cases} f(x_{ij}) < B_i \\ \sum_{i=1}^{6} f(x_{ij}) < A \end{cases} (i = 1,...,6; j = 1,...,7) \tag{13}$$

The results of daily supply and pricing for each category are obtained as shown in Tables 2, 3 and 4:

Table 2. Decision Options for Pricing ($/kg) for Vegetable Categories for the Week Ahead

Date/ Category	7-1	7-1	7-3	7-4	7-5	7-6	7-7
philodendron	3.59878	3.23792	4.49848	5.04773	6.19481	3.58309	4.08530
capsicum	33.5240	29.2509	29.8016	20.4376	37.2333	26.9440	27.9564
edible mushroom	5.67102	6.56336	6.46254	9.40494	8.11342	6.69117	6.19043
cauliflower	7.60679	7.15692	8.07432	13.0367	9.65019	8.95214	8.93032
aquatic rootstock	25.1497	11.5918	18.8145	18.7907	15.2748	10.6600	10.6258
eggplant	14.8142	7.58039	12.9313	16.1698	9.31790	8.90309	8.57476

Table 3. Decision scenarios for daily replenishment (kg) of vegetable categories in the coming week

Date/ Category	7-1	7-2	7-3	7-4	7-5	7-6	7-7
philodendron	196.156	260.357	279.824	157.745	265.881	249.373	213.224
capsicum	72.144	102.857	104.551	45.392	109.527	105.927	76.687
edible mushroom	65.301	62.512	27.253	49.109	48.763	61.731	58.065
cauliflower	51.854	20.122	42.445	41.765	53.824	31.75	26.875
aquatic rootstock	21.927	10.828	10.761	7.709	14.794	12.424	12.155
eggplant	10.091	8.932	7.322	9.935	4.395	7.624	5.653

Table 4. Cost Plus Ratio (%) for Vegetable Categories for the Week Ahead

Date/ Category	7-1	7-2	7-3	7-4	7-5	7-6	7-7
philodendron	37.06	50.70	69.21	50.12	85.25	21.75	32.74
capsicum	71.56	108.24	110.26	36.42	107.24	103.63	74.45
eggplant	98.68	26.75	78.66	113.43	108.78	91.87	90.77
edible mushroom	22.28	83.27	81.71	100.96	90.16	117.28	54.90
cauliflower	56.22	43.27	48.31	99.61	55.63	42.45	52.17
aquatic rootstock	87.06	36.00	80.56	26.67	46.21	35.19	35.56

3. Conclusion

This paper addresses the need for supermarkets to automate pricing and replenishment of vegetable products, through the integration and analysis of different vegetable data, based on dynamic programming to establish a single-objective optimization model for supermarkets to develop decision-making solutions to meet the needs of consumers to meet the supermarkets to maximize revenue. This paper firstly constructs a nonlinear regression model to fit the function of pricing and daily sales volume of vegetable categories, and finds that the two have negative correlation; secondly, this paper predicts the cost of each category of vegetables in the coming week by establishing a grey time series prediction model; finally, this paper takes the pricing of different categories on different dates as the decision variables, maximizes the revenue of the superstore as the objective function, and maximizes the capacity of categories as the constraints to establish a single-objective planning model, which is based on dynamic planning. constraints to establish a single-objective planning model, based on the dynamic programming algorithm, using the idea of iteration to determine the optimal daily replenishment and pricing decisions.

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