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Prediction of China's Grain Consumption from the Perspective of Sustainable Development—Based on GM(1,1) Model

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Abstract: Being the largest producer and consumer of grain in the world, China occupies an extremely important position in the world grain market. The grain security of China is confronted with such problems as shortages of water and soil resources, a fragile ecological environment, and infrastructure constraints. The prediction and analysis of China's grain consumption is conducive to establishing a resource-saving grain production mode, a sustainable grain supply and demand system, and a national grain security guarantee system at a higher level. In order to judge the future development trend of China's grain accurately, guide grain production, stabilize grain expectation, and serve the relevant decision making of grain security, the GM(1,1) prediction model of China's grain consumption has been constructed in this paper. Prediction research has been conducted with the grain consumption structure as the entry point. The model has high prediction accuracy and can be used for medium- and long-term prediction of China's grain consumption after testing. The prediction results show that China's grain consumption will continue to increase from 2022 to 2031, which is consistent with the factors of population change, urbanization promotion, consumption structure upgrading, and so on, in the country. Among the different types of consumption, the change in eating consumption will be small, the growth in feeding consumption and squeezing (soybean) consumption will slow down, industrial consumption will increase steadily, and seed consumption will be basically stable.

Keywords: food security; food consumption; sustainable; GM(1,1) model; prediction

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1. Introduction

Grain security concerns the overall economic development strategy of a country and is an important foundation for social stability and national security. Currently, the grain security of China is confronted with such problems as shortages of water and soil resources, a fragile ecological environment, and infrastructure constraints [1,2]. Meanwhile, factors including globalization, urbanization, climate change, COVID-19, regional conflicts, and the goals of "carbon peaking and carbon neutrality" have also posed great challenges and impacts to China's grain security [3–5]. Balancing environmental protection and grain security, meeting people's reasonable nutritional requirements and the resource and environmental constraints, and realizing the sustainability of the grain supply are urgent issues for China [6,7].

Prediction can effectively depict the process of future changes. It is greatly applicable for highly complex and uncertain fields, such as strategic planning, policy analysis, and decision management. It is an important type of prospective study [8]. The prediction of grain consumption prospects (trend and quantity) is essential for a country in the formulation of long-term economic and social planning and in the medium- and long-term prediction of economic and social changes [9]. The prediction and analysis of China's grain consumption is conducive to gearing production to demand, matching them accurately, and establishing a healthy and diversified dietary consumption pattern and resource-saving

grain production mode [10]. It is helpful for breaking through the constraints of complex factors related to grain supply and demand and setting up a national grain security guarantee system at a higher level [11]. It is also helpful for the government to accurately grasp the changing trend of grain security and make reasonable grain management decisions. Therefore, it is of great significance for guiding China's future grain production, improving its ability to regulate the grain market, and building a sustainable grain supply and demand system [12,13].

Many domestic and foreign scholars have established different ideas and adopted different methods to carry out research on the prediction of China's grain consumption. Early studies were mostly qualitative ones based on empirical judgment, such as expert judgment and factor analysis [14,15]. Their prediction results were highly subjective due to the differences in basic data used by researchers, the key factors considered, and the researchers' understanding of the history, current situation, and future. Subsequently, scholars mostly adopted quantitative study designs based on mathematical models such as time series and simultaneous supply–demand equations [16–18]. These methods rely on historical data and data formats and have the disadvantages of short prediction period, lack of theoretical basis, and limited application scenarios. Some scholars have used the nutritional requirement method and system dynamics model to estimate China's future grain consumption [19,20]. These two methods lack a solid economic analysis framework and an ability to accurately grasp the change of demand function in the process of economic development. Existing studies have the following problems: most of them are trend prediction studies and have great differences in the judgment of medium- and long-term grain consumption; in addition, most of the studies only give the total demand for grain and do not take into account the variety difference of grain and the change of consumption structure.

There are many complex uncertain factors affecting China's grain consumption, so it is a great challenge to select an appropriate model method for accurate prediction. GM(1,1) is a single-sequence prediction model that solves the analysis, prediction, decision making, and control of systems with "small sample size, poor information, and uncertainty", without considering the role of factors other than behavioral variables [21,22]. It has a high accuracy in predicting and analyzing future development trends by using existing data; has been widely applied in agriculture, industry, hydrology, energy, and economy; and has successfully solved a large number of practical problems [23,24]. One characteristic of the GM(1,1) model is that it requires little information. It is able to transform a disordered discrete original sequence into an ordered sequence to maintain the features of the original system and better reflect the actual changes of the system [25,26]. The characteristics of the GM(1,1) model perfectly meet the needs of the prediction of China's grain consumption, so this model is adopted in the research.

At present, China's economic growth is slowing down. Natural disasters, regional conflicts, and other factors will have a great impact on global grain production and trade. Considering other superimposed factors, such as global excess liquidity and natural disasters in some major producing countries, international grain prices will surge. In order to solve the above problems and enhance the stability of China's grain system, it is urgent to accurately judge the future development trends of China's grain. In this paper, the consumptions of main grain varieties in China from 2010 to 2021 are taken as the basic data to build a GM(1,1) prediction model of China's grain consumption, and the accuracy of the model is tested. The test results show that the GM(1,1) model built in the paper has a high prediction accuracy and can be used to predict and study China's grain consumption. Therefore, the model is used to predict and analyze China's grain consumption over the next 10 years. The rest of the paper is arranged as follows: the second part describes the principle and modeling steps of GM(1,1); in the third part, the GM(1,1) prediction model of China's grain consumption is built, its accuracy is tested, and China's grain consumption over the next 10 years is predicted; the fourth part summarizes the whole paper and looks forward to the next research direction.

2. Materials and Methods

2.1. Basic Principle of GM(1,1) Model

GM(1,1) is suitable for complex problems of systems with incomplete information and small sample size. Its basic idea is to develop a correct understanding of the research object by generating and developing part of the unknown information and mining key information hidden in the known data [27–29].

2.1.1. Modeling Conditions

Let sequence X = (x (1), x (2), . . . , x (n)), and σ(k) = $\frac{x\ (k)}{x\ (k-1)}$; k = 2, 3, . . . , and let n be the step ratio of sequence X. When the step ratio of original time series data σ(k) ∈ ($e^{-\frac{2}{n+1}}, e^{\frac{2}{n+1}}$), a satisfactory GM(1,1) model can be built [30,31].

2.1.2. Process the Original Sequence

Suppose $x^{(0)}$ = ($x^{(0)}$(1), $x^{(0)}$(2), . . . , $x^{(0)}$(n)) is a non-negative quasi-smooth sequence; carry out 1-AGO (1-order accumulated generating operation) on the original sequence x(0), and obtain the following sequence:

$$x^{(1)} = (x^{(1)}(1), x^{(1)}(2), \ldots, x^{(1)}(n)) \quad (1)$$

In Equation (1), $x^{(1)}$(k) = $\sum_{i=0}^{k} x^{(0)}(i)$, k = 1, 2, . . . ,n.

2.1.3. Process the Newly Generated Sequence x(1)

Perform neighbor generation for sequence x(1), and obtain the following sequence:

$$z^{(1)} = (z^{(1)}(2), z^{(1)}(3), \ldots, z^{(1)}(n)) \quad (2)$$

In Equation (2), $z^{(1)}$(k) = 0.5($x^{(1)}$(k) + $x^{(1)}$(k − 1)), k = 2, 3, . . . , n.

2.1.4. Establish and Solve the Grey Differential Equation

Suppose $x^{(0)}$(k) + a $z^{(1)}$(k) = b is the grey differential equation of the GM(1,1) model. The classical grey modeling process uses the least square method to estimate the parameter vector of the GM(1,1) model, as follows:

$$\hat{A} = (a,b)^T = (B^TB)^{-1}B^TY \quad (3)$$

In Equation (3), $Y = \begin{bmatrix} x^0(2) \\ x^0(3) \\ \cdots \\ x^0(n) \end{bmatrix}$; $B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \cdots & \cdots \\ -z^{(1)}(4) & 1 \end{bmatrix}$.

Corresponding to the grey differential equation of the GM(1,1) model, there is a whitening differential equation:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = b \quad (4)$$

The time response function of the GM(1,1) model is obtained by solving the whitening differential equation as follows:

$$\hat{x}^{(1)}(t) = \frac{b}{a} + (x^{(0)}(1) - \frac{b}{a})e^{-a(t-1)} \quad (5)$$

The time response sequence of the GM(1,1) model is obtained through the discretization of Equation (5):

$$\hat{x}^{(1)}(k) = \frac{b}{a} + (x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)},\ k = 2, 3, \ldots, n \quad (6)$$

Finally, perform 1-order accumulated reduction on $\hat{x}^{(1)}(k)$, and obtain the final simulated predicted value:

$$\hat{x}^{(0)}(k) = \hat{x}^{(1)}(k) - \hat{x}^{(1)}(k-1),\ k = 2, 3, \ldots, n \tag{7}$$

In Equation (6), parameter -a is the development coefficient with a range of (−2,2), which reflects the dynamic relationship between the behavioral variable of the system and its background value, and when $-a \leq 0.3$, GM(1,1) can be used for medium- and long-term prediction; b is the grey action, which is not only the concrete embodiment of the connotation extension of the grey system, but also an important symbol to distinguish the grey modeling from the input–output modeling in the black box [32,33].

2.2. Accuracy Tests on the Model

A scientific and reasonable GM(1,1) model needs to not only meet its initial modeling conditions, but also pass three model accuracy tests, namely residual test, posterior error test, and small error probability test, before it is applied to actual prediction. The accuracy grade confirmation of a model is shown in Table 1 [34,35].

Table 1. Standards for model accuracy tests.

Accuracy Grade	MAPE	C	P
1	10%<	≤0.35	0.95≤
2	10%~<20%	0.35~≤0.5	0.8~<0.95
3	20%~<50%	0.5~<0.65	0.7~≤0.8
4	≥%	≥0.65	≤0.7

Notes: The accuracy grade of the model = max{grade of $\overline{\Delta}$, grade of C, grade of P}; 1 means the model is "excellent", 2 means it is "qualified", 3 means it is "barely satisfactory", and 4 means it is "unqualified" [36].

2.2.1. Residual Test

For the original and newly generated sequences, let residual $\varepsilon(k) = x^{(0)}(k) - \hat{x}^{(0)}(k)$, and relative error $\Delta(k) = \frac{|\varepsilon(k)|}{x^{(0)}(k)}$. The average relative error is as follows:

$$\text{MAPE} = \frac{1}{n}\sum_{k=1}^{n}\Delta(k),\ k = 1, 2, \ldots, n \tag{8}$$

2.2.2. Posterior Error Test

The mean value and mean square error of the original sequence are as follows:

$$\overline{x^{(0)}} = \frac{1}{n}\sum_{k=1}^{n}x^{(0)}(k),\ k = 1, 2, \ldots, n \tag{9}$$

$$S_0^2 = \frac{1}{n-1}\sum_{k=1}^{n}\left(x^{(0)}(k) - \overline{x^{(0)}}\right)^2,\ k = 1, 2, \ldots, n \tag{10}$$

The mean value and mean square error of the residual are as follows:

$$\overline{\varepsilon(k)} = \frac{1}{n}\sum_{k=1}^{n}\varepsilon(k),\ k = 1, 2, \ldots, n \tag{11}$$

$$S_1^2 = \frac{1}{n-1}\sum_{k=1}^{n}\left(\varepsilon(k) - \overline{\varepsilon(k)}\right)^2,\ k = 1, 2, \ldots, n \tag{12}$$

The posterior error ratio C is as follows:

$$C = \sqrt{\frac{S_1^2}{S_0^2}} \tag{13}$$

2.2.3. Small Error Probability Test

The calculation formula of the small error probability is as follows:

$$P = p\left\{ \mid \varepsilon(k) - \overline{\varepsilon(k)} \mid < 0.6745S_0 \right\} \quad (14)$$

3. Results

3.1. Data Description

The main grain varieties consumed by Chinese residents are rice, wheat, corn, and soybean, and the consumption structure is composed of eating consumption, feeding consumption, industrial consumption, seed consumption, and squeezing (soybean) consumption. In the existing national statistical data, there are many data about grain production but a tremendous lack of statistical data on the grain consumption by variety and the consumption structure. The original consumption data of rice, wheat, corn, and soybean used in the model in this paper are from the China Agricultural Outlook (2014–2022) published by the Market Early Warning Expert Committee of the Ministry of Agriculture and Rural Affairs, PRC, as shown in Table 2. It can be found that since 2010, China's grain consumption has shown a rigid growth, with an average annual growth rate of 1.51%; eating consumption and feeding consumption account for a large proportion of the total, the proportions of industrial consumption and squeezing consumption have increased year by year, and seed consumption has changed little.

Table 2. Main grain consumptions of China (2010–2021). Unit: millions of tons.

Year	Food Consumption	Feed Consumption	Industry Consumption	Seed Consumption	Squeezing Consumption
2010	253.95	172.47	80.40	9.61	61.94
2011	254.12	175.95	83.36	9.89	65.67
2012	255.23	179.56	85.37	10.00	67.99
2013	256.49	179.61	86.99	10.08	70.81
2014	257.25	181.57	91.01	10.21	69.92
2015	258.25	187.36	94.25	10.40	71.37
2016	259.77	190.79	97.40	10.55	74.58
2017	261.36	193.73	99.58	10.92	75.12
2018	261.48	199.74	101.32	10.87	78.60
2019	262.12	204.57	101.23	10.91	80.45
2020	264.39	208.79	103.01	10.93	81.85
2021	264.44	218.36	104.71	11.03	83.20

Data sources: China Agricultural Outlook (2022–2031) [37]. Notes: Squeezing consumption mainly refers to soybean; other consumptions, such as grain loss, are not included.

3.2. Building and Application of the GM(1,1) Model of China's Grain Consumption

3.2.1. Step Ratio Test on the Original Data before Modeling

Carry out the step ratio test on the original data in Table 2 to judge whether they meet the modeling conditions of GM(1,1). According to the calculation, the minimum value minσ = 0.9875 and the maximum value maxσ = 1.0601 of the step ratio of original time series data fall within the range of $(e^{-\frac{2}{13}}, e^{\frac{2}{13}})$, so a satisfactory GM(1,1) model can be built.

3.2.2. Calculation of Model Parameters to Be Estimated

The function of the time response sequence is as follows:

$$\hat{x}^{(1)}(k) = \frac{b}{a} + (x^{(0)}(1) - \frac{b}{a})e^{-a(k-1)},\ k = 2, 3, \ldots, 12 \quad (15)$$

The parameters to be estimated in Equation (15) (i.e., development coefficient -a and grey action b) are calculated using MATLAB 9.9. Through calculation, the parameters

(see Table 3) and their formulas in the GM(1,1) prediction model for the four main grain consumptions in China are as follows:

$$\hat{x}^{(1)}_{Fo-C}(k) = 62101.492e^{0.004086(k-1)} - 61847.5404,\ k = 2,\ 3,\ \ldots,\ 12 \quad (16)$$

$$\hat{x}^{(1)}_{Fe-C}(k) = 8037.3836e^{0.02128(k-1)} - 7864.9184,\ k = 2,\ 3,\ \ldots,\ 12 \quad (17)$$

$$\hat{x}^{(1)}_{In-C}(k) = 3606.4371e^{0.023196(k-1)} - 3526.0338,\ k = 2,\ 3,\ \ldots,\ 12 \quad (18)$$

$$\hat{x}^{(1)}_{Se-C}(k) = 834.2827e^{0.011815(k-1)} - 824.6765,\ k = 2,\ 3,\ \ldots,\ 12 \quad (19)$$

$$\hat{x}^{(1)}_{Sq-C}(k) = 2763.3209e^{0.023611(k-1)} - 2701.3778,\ k = 2,\ 3,\ \ldots,\ 12 \quad (20)$$

Table 3. Parameter values of the GM(1,1) prediction model of China's grain consumption.

Parameter	Food Consumption	Feed Consumption	Industry Consumption	Seed Consumption	Squeezing Consumption
−a	−0.004086	−0.021280	−0.023196	−0.011815	−0.023611
b	252.709050	167.365463	81.789879	9.743553	63.782232

Perform 1-order accumulated reduction on $\hat{x}^{(1)}_{Fo-C}(k)$, $\hat{x}^{(1)}_{Fe-C}(k)$, $\hat{x}^{(1)}_{In-C}(k)$, $\hat{x}^{(1)}_{Se-C}(k)$, and $\hat{x}^{(1)}_{Sq-C}(k)$, respectively, to obtain the simulated values of rice, wheat, corn, and soybean consumptions in China during 2010–2021, as shown in Table 4.

Table 4. Original and simulated values of main grain consumptions in China during 2010–2021. Unit: millions of tons.

Year	Food Consumption		Feed Consumption		Industry Consumption		Seed Consumption		Squeezing Consumption	
	OV	PV	OV	PV	OV	PV	OV	PV	OV	PV
2010	253.95	253.95	172.47	172.47	80.40	80.40	9.61	9.61	61.94	61.94
2011	254.12	254.27	175.95	172.87	83.36	84.63	9.89	9.92	65.67	66.02
2012	255.23	255.31	179.56	176.59	85.37	86.62	10.00	10.03	67.99	67.60
2013	256.49	256.35	179.61	180.38	86.99	88.65	10.08	10.15	70.81	69.21
2014	257.25	257.40	181.57	184.26	91.01	90.73	10.21	10.27	69.92	70.87
2015	258.25	258.46	187.36	188.23	94.25	92.86	10.40	10.40	71.37	72.56
2016	259.77	259.51	190.79	192.28	97.40	95.04	10.55	10.52	74.58	74.29
2017	261.36	260.58	193.73	196.41	99.58	97.27	10.92	10.64	75.12	76.07
2018	261.48	261.64	199.74	200.64	101.32	99.55	10.87	10.77	78.60	77.89
2019	262.12	262.72	204.57	204.95	101.23	101.89	10.91	10.90	80.45	79.75
2020	264.39	263.79	208.79	209.36	103.01	104.28	10.93	11.03	81.85	81.65
2021	264.44	264.87	218.36	213.86	104.71	106.73	11.03	11.16	83.20	83.60

Notes: OV means original value; PV means predicted value.

3.2.3. Accuracy Test on the GM(1,1) Model of China's Grain Consumption

To verify the scientificity and rationality of the GM(1,1) prediction model of China's grain consumption built in this research, in addition to the step ratio test on the original data, the residual test, posterior error test, and small error probability test also need to be carried out on the model to determine its accuracy grade. According to the accuracy confirmation principle of the model in Table 1, the GM(1,1) prediction model of China's grain consumption built here has a high prediction accuracy, and its grade is 1 (excellent). See Table 5 for the accuracy test results. The model can be used to predict China's consumptions of rice, wheat, corn, and soybean in the medium and long term.

Table 5. Accuracy test on the GM(1,1) model of China's grain consumption.

Accuracy Assessment	Food Consumption	Feed Consumption	Industry Consumption	Seed Consumption	Squeezing Consumption
MAPE	0.12%	0.99%	1.54%	0.72%	0.96%
C	0.11	0.16	0.19	0.23	0.12
P	1.00	1.00	1.00	1.00	1.00

3.3. Prediction of China's Grain Consumption

According to the GM(1,1) prediction model built above, China's grain consumption over the next 10 years (2022–2031) is predicted, and the results are shown in Table 6 and Figure 1. As revealed by the prediction results, based on 2021, the grain consumption will continue to increase at an average annual growth rate of 1.53% over the next 10 years. Among the consumptions, the change in eating consumption will be small, the growth in feeding consumption and squeezing (soybean) consumption will slow down, industrial consumption will increase steadily, and seed consumption will be basically stable.

Table 6. China's grain consumption forecast for 2022–2031. Unit: millions of tons.

Year	Food Consumption	Feed Consumption	Industry Consumption	Seed Consumption	Squeezing Consumption
2022	265.96	218.46	109.23	11.29	85.6
2023	267.04	223.16	111.8	11.43	87.65
2024	268.14	227.96	114.42	11.56	89.74
2025	269.24	232.86	117.1	11.7	91.88
2026	270.34	237.87	119.85	11.84	94.08
2027	271.45	242.99	122.67	11.98	96.33
2028	272.56	248.21	125.54	12.12	98.63
2029	273.67	253.55	128.48	12.27	100.98
2030	274.79	259.01	131.51	12.41	103.4
2031	275.92	264.58	134.59	12.56	105.87

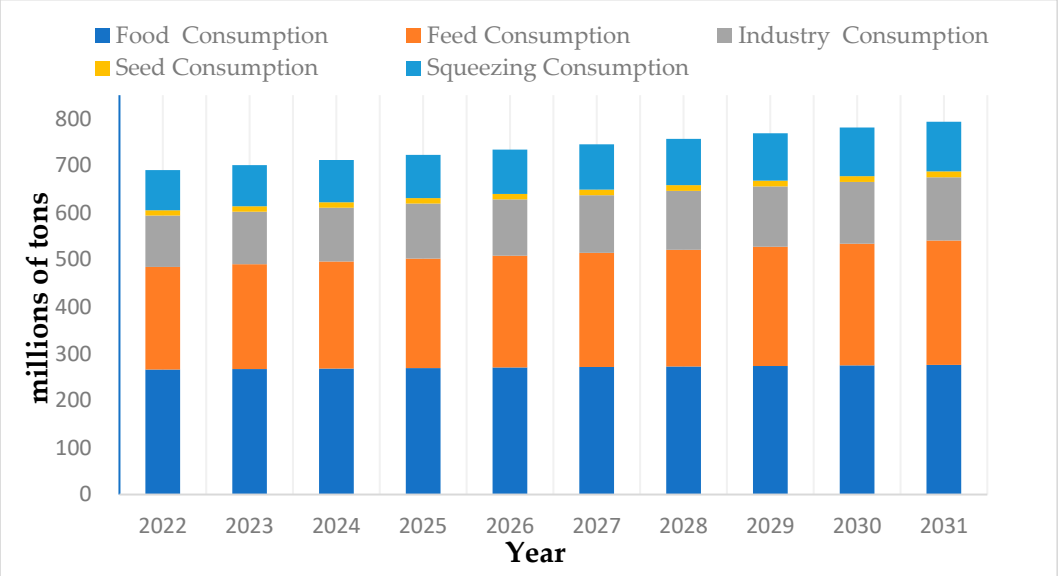


Figure 1. Changing trend of China's grain consumption during 2022–2031.

3.4. Discussion

Research shows that grain consumption will continue to show rigid growth, and supply and demand of grain will be in a tight balance for a long time in China. It is estimated that grain consumption will reach 690.5 million tons in 2022 and 745.4 million

tons in 2027. The average annual growth rate is 1.53% over the next 10 years. With the improvement of residents' income level, the dietary structure will change in a more balanced and reasonable direction, and the demand for meat, eggs, milk, vegetables, and fruits will further increase the substitution effect of ration consumption. The consumption of rations will remain basically stable, with an average annual growth rate of 0.38% over the next 10 years. Due to the impact of the increase in the consumption of animal products on the demand for feed, the consumption of grain feed will continue to show an upward trend. It is estimated that the consumption of grain will be 218.4 million tons in 2022 and 243.0 million tons in 2027, with an average annual growth rate of 1.94% over the next 10 years.

Industrial consumption of grain mainly includes wine making, condiments, sauces, preparations, and pharmaceuticals. With the continuous development of the food industry and fermentation industry, and the expansion of fuel ethanol and biodiesel production, the demand for industrial consumption of grain will show a stable growth trend. It is estimated that the consumption of the grain industry will be 109.2 million tons in 2022 and 122.7 million tons in 2027, with an average annual growth rate of 2.54% over the next 10 years. The crushing consumption of soybeans will continue to increase to meet the domestic demand for feed protein raw materials and edible vegetable oil. It is estimated that the crushing consumption will be 83.2 million tons in 2022, 96.3 million tons in 2027, and 105.9 million tons in 2031. The planting consumption is mainly affected by the sown area of grain. During the forecast period, the planting consumption of grain will basically remain at about 12 million tons.

China's food security is closely related to world food security, and China is a positive force in safeguarding world food security. To predict and study China's grain consumption, determining production based on demand, accurately matching them, and establishing a healthy, diversified dietary consumption mode and resource-saving grain production mode are conducive to improving China's and even the world's food security level. Many experts and research institutions have conducted prediction research on grain consumption in China, and the research results are also different. Yuan Chen and Changhe Lu [38] believed that China's grain consumption is expected to increase with the growth of the population and residents' income. Lu Wen Cong et al. [39] used the Chinese World Agricultural Regional Market Equity Model (CWARMEM) to predict and analyze the supply and demand of grain in China. Results showed that the level of urbanization will promote the upgrading of China's grain security. In addition, based on statistical data and the China Agricultural Industry Model (CASM), the Chinese Academy of Agricultural Development Strategies predicted the development trend of agriculture and food systems in China. The results showed that China's grain consumption will continue to increase from 2021 to 2035 with the rapid growth of feed demand and industrial demand [40]. Since 1999, the OECD and FAO have jointly issued the OECE-FAO Agricultural Outlook every year. Based on the Aglink-Cosimo prediction model, the annual OECE-FAO Agricultural Outlook is devoted to informing policymakers on the future development trends of agriculture and food, including reliable information of the driving factors affecting global demand, supply, trade, and price. According to the data of OECE-FAO Agricultural Outlook 2022–2031, the consumption of rations in low-income countries will continue to increase, and the consumption of feed grains in middle-income and high-income countries will continue to increase over the next 10 years [41]. The judgment of this paper on the change trend of China's grain consumption is basically consistent with the above research, but it uses a different perspective and different research methods from the above research. From the perspective of research on the structure of grain consumption, this research is more detailed, and the prediction model has also passed the test perfectly, which greatly add to and enrich the existing research results.

4. Conclusions

Grain security has a bearing on the national economy and on people's livelihood. It is not only affected by supply, but also by various policies on agriculture, science, and

technology. Closely related to consumer demand at the stage of social and economic development, it is a complex systemic issue that covers a large number of people and involves a wide range of industries. Against the realistic background of overlapping domestic and foreign risks, only a clear understanding of China's grain supply and demand situation and the development of a sustainable food system can help China establish a better grain supply mode and improve the grain security guarantee system under the conditions of a large population, little land, and hard constraints of resources and environment [42]. In the existing national statistical data of grain supply and demand, there are sufficient data on grain production but a serious lack of grain consumption data, resulting in blindness and fluctuation in production.

Based on this, in order to scientifically grasp the development trend of grain consumption and establish a grain supply and demand guarantee system, in this paper, the GM(1,1) prediction model of China's grain consumption has been built and proven to have a high prediction accuracy, so it can be used for the medium- and long-term prediction of grain consumption in China. According to the forecast results of China's grain consumption from 2022 to 2031, it can be seen that China's grain consumption will show a continuous growth trend, and the grain supply and demand will be in a tight balance for a long time over the next 10 years, which is consistent with China's population growth, urbanization promotion, consumption structure upgrading, and other factors. From the perspective of grain trade, as the domestic grain supply is still tight, there is a price difference between domestic and foreign grain, and domestic consumers' demand for high-quality grain products has been increased significantly. These factors will keep the scale of grain trade at a high level, but the import volume will show a steady downward trend. In terms of grain prices, with the promotion of the reform of the grain storage system and the price formation mechanism, the market will play a decisive role in the allocation of grain resources. Grain prices will reflect market supply and demand precisely and maintain a reasonable price level.

Based on the research results of this paper, the next research will focus on how to balance environmental protection, grain security, and farmers' income increase, and how to achieve sustainability of the grain supply in China on the premise of meeting reasonable nutritional requirements and the resource and environmental constraints. In addition, in the aspect of model research, the background value and initial conditions of the GM(1,1) model will be comprehensively optimized to improve the prediction accuracy and stability of the model.

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References

1. Cui, K.; Shoemaker, S.P. A look at food security in China. *NPJ Sci. Food* **2018**, *4*, 2–4. [CrossRef]
2. Zhong, S.J. Research on the development path of China's grain industry from the perspective of sustainable development. *Rural Econ.* **2022**, *02*, 28–29.
3. Fukase, E.; Martin, W. Who Will Feed China in the 21st Century? Income Growth and Food Demand and Supply in China. *J. Agric. Econ.* **2016**, *67*, 1, 3–23. [CrossRef]
4. Huang, J.K.; Wei, W.; Cui, Q.; Xie, W. The prospects for China's food security and imports: Will China starve the world via imports? *J. Integr. Agric.* **2017**, *16*, 2933–2944. [CrossRef]
5. Si, W.; Zhang, Y.M.; Fan, S.G. How to Ensure Food and Nutrition Security under the COVID—19 Epidemic: A Global Perspective. *Issues Agric. Econ.* **2020**, *3*, 11–16.
6. Cheng, S.K.; Dong, J.C.; Liu, Z.Y.; Ren, Z.G.; Liu, X.L.; Liu, X.J.; Zong, G.; Li, X.T.; Deng, X.Z. Key Scientific Issues on National Nutrition and Food Security in China in the New Era: Summary of the 249th NSFC Shuangqing Forum. *Bull. Natl. Nat. Sci. Found. China* **2021**, *35*, 426–434.
7. Liang, X.Y.; Jin, X.B.; Sun, R.; Han, B.; Ren, J.; Zhou, Y.K. China's resilience-space for cultivated land protection under the restraint of multi-scenario food security bottom line. *Acta Geogr. Sin.* **2022**, *77*, 697–713.
8. Xing, Y.; Dong, Y.; Yuan, J.X.; Zhang, B.; Yang, Y.P.; Zhang, W. Investigation of Scenario Analysis in Typical Agricultural. *Libr. Inf. Serv.* **2014**, *58*, 95–99.
9. Mi, J.; Luo, Q.Y.; Gao, M.J. A review on food demand forecast methods. *Chin. J. Agric. Resour. Reg. Planning.* **2013**, *34*, 28–33.
10. Liu, Y.; Luo, Q.Y.; Zhou, Z.Y.; You, F.; Gao, M.J.; Tang, Q. Analysis and Prediction of the Supply and Demand of China's Major Agricultural Products. *Strateg. Study CAE* **2018**, *20*, 120–127. [CrossRef]
11. Fan, S.G.; Long, W.J.; Feng, X.L.; Si, W.; Sheng, Y. The UN Food Systems Summit and Chinese Strategy. *Issues Agric. Econ.* **2022**, *03*, 4–16.
12. Fan, S.G.; Zhang, Y.M.; Chen, K.Z. Antiglobalism and Global Food Security. *Issues Agric. Econ.* **2019**, *3*, 4–10.
13. Chen, R.S.; Guo, X.N.; Xiong, B.; Wang, Y.; Chen, Q. Climate change, land degradation and food insecurity: Linkages and potential solutions. *Acta Ecol. Sin.* **2021**, *41*, 2918–2929.
14. Brown, L.R. *Who Will Feed China? Wake-Up Call for a Small Planet?* World Watch Norton and CO: New York, NY, USA, 1995; pp. 1–163.
15. Cheng, G.Q.; Chen, L.B. Long term trend of grain demand in China. *China Rural Surv.* **1998**, *03*, 3–8+13.
16. Zhu, X.G. Analysis on the balance of grain supply and demand in China. *Issues Agric. Econ.* **2004**, *12*, 12–19.
17. Lu, W.C.; Huang, Z.H. Future Prospects of Grain Supply and Demand in China: A Regionalized Multimarket Model Simulation. *Econ. Res. J.* **2004**, *08*, 94–104.
18. Luo, Q.Y.; Mi, J.; Gao, M.J. Research on Forecasting for Long-term Grain Consumption Demands in China. *Chin. J. Agric. Resour. Reg. Plan.* **2014**, *35*, 1–7.
19. Chen, K.; Bi, J.Y.; Nie, F.Y.; Fang, X.M.; Fan, S.G. New Vision and Policy Recommendations for Nutrition-Oriented Food Security in China. *Sci. Agric. Sin.* **2019**, *52*, 3097–3107.
20. Gong, B.; Yin, F.Y. Measurement of the Impact of Urbanization on China's Grain Consumption. *Theory Pract. Financ. Econ.* **2018**, *39*, 134–140.
21. Zhang, X.Y.; Li, Z.M. GM(1,1) Model-based Sown Area Prediction of Minor Grains in China. *Chin. J. Agric. Resour. Reg. Plan.* **2018**, *39*, 81–86.
22. Xu, Y.; Yang, Z.G. A Projection of Participation Rate of Basic Pension Insurance for Urban and Rural Residents Based on the Grey GM(1,1) Model. *Insur. Stud.* **2019**, *4*, 116–127.
23. Lu, S.S.; Yu, J.S. Research on Shanghai Vegetable Yield Forecasting Based on Grey Mode GM(1,1). *Chin. Agric. Sci. Bull.* **2014**, *30*, 255–260.
24. Ni, C. The application of the GM(1,1) model on the prediction of sustainable land use in Hulan District (County) of Harbin City. *Territ. Nat. Resour. Study* **2010**, *1*, 40–41.
25. Sun, X.R.; Zhang, C. Analysis of population development trend in China based on GM(1,1) model. *Stat. Decis.* **2016**, *23*, 104–106.
26. Dai, S.Y.; Niu, D.X.; Han, Y.R. Forecasting of Energy-Related CO_2 Emissions in China Based on GM(1,1) and Least Squares Support Vector Machine Optimized by Modified Shuffled Frog Leaping Algorithm for Sustainability. *Sustainability* **2018**, *10*, 958. [CrossRef]
27. Gao, X.C.; Shi, P.J.; Pan, J.H.; Lv, L.G. A Case Study of Tianshui City in Gansu: Plantation Preservation Quantity Research Based on Food Security and GM(1,1) Model. *Syst. Sci. Compr. Stud. Agric.* **2011**, *27*, 407–412.
28. He, B.; Zhu, L.X. Grey System Theory GM(1,1) Model and Its Application to Tourism Industry Revenue Forecasting-Take Hainan Province as an Example. *Torism Forum* **2011**, *4*, 68–70, 102.
29. Ma, N.S.; Zhi, X.J.; Song, Y.T. Evaluation and prediction of the cultivated land ecological security in Tibet based on PSR and GM(1,1) model. *J. Arid Land Resour. Environ.* **2018**, *32*, 81–86.
30. Yu, S.; Dong, M. Sustainable development of China's regions from the perspective of ecological welfare performance: Analysis based on GM(1,1) and the malmquist index. *Environ. Dev. Sustain.* **2022**, *24*, 1086–1115.
31. Wang, C.N.; Hsu, H.P.; Wang, J.W.; Kao, Y.C.; Nguyen, T.P. Strategic Alliance for Vietnam Domestic Real Estate Companies Using a Hybrid Approach Combining GM(1,1) with Super SBM DEA. *Sustainability* **2020**, *12*, 1891. [CrossRef]

32. Li, P.; Liu, J.; Wei, C.P. A Dynamic Decision Making Method Based on GM(1,1) Model with Pythagorean Fuzzy Numbers for Selecting Waste Disposal Enterprises. *Sustainability* **2019**, *11*, 5557. [CrossRef]
33. Tang, T.; Jiang, W.H.; Zhang, H.; Nie, J.T.; Xiong, Z.H.; Wu, X.G.; Feng, W.J. GM(1,1) based improved seasonal index model for monthly electricity consumption forecasting. *Environ. Dev. Sustain.* **2022**, *24*, 1086–1115. [CrossRef]
34. Lv, L.G.; Shi, P.J.; Pan, J.H.; Zeng, C.P. Plantation Preservation Quantity Research Based on Food Security and GM(1,1) Model-A Case Study of Tianshui City in Gansu. *Syst. Sci. Compr. Stud. Agric.* **2010**, *26*, 91–96.
35. Tian, S.L.; Lu, L.J. Big data gray system GM(1,1) model application for coal research and development strategies in Jilin. *Geol. Bull. China* **2015**, *34*, 1369–1374.
36. Ran, Q.H.; Yue, Y.H.; Luo, H.Y.; Xie, D.T.; Wei, C.F. The Model of Grain Demand-Supply Based on Population Curve Fit and GM(1,1) and Empirical Analysis. *J. Southwest China Norm. Univ. (Nat. Sci. Ed.)* **2009**, *34*, 115–121.
37. Market Early Warning Expert Committee of Ministry of Agriculture and Rural Affairs. *China Agricultural Outlook (2022–2031)*; China Agricultural Science and Technology Press: Beijing, China, 2022; pp. 1–172.
38. Chen, Y.; Lu, C. Future Grain Consumption Trends and Implications on Grain Security in China. *Sustainability* **2019**, *11*, 5165. [CrossRef]
39. Lu, W.-C.; Chen, N.-L.; Qian, W.-X. Modeling the effects of urbanization on grain production and consumption in China. *J. Integr. Agric.* **2017**, *16*, 1393–1405. [CrossRef]
40. Chinese Academy of Agricultural Sciences. *China Agricultural Sector Development Report*; China Agricultural Science and Technology Press: Beijing, China, 2021.
41. OECD/FAO. *OECD-FAO Agricultural Outlook 2022–2031*; OECD Publishing: Paris, France, 2022. [CrossRef]
42. Yang, Y.; He, D.F.; Tong, H.F.; Wang, J.Y.; Qu, W.S.; Li, Y.Y. Demand and Supply of Chinese Cereal Based on T21 China Model. *China Soft Sci.* **2013**, *12*, 32–44.