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Analysis of Dynamic Changes and Main Obstacle Factors of Grain Supply and Demand Balance in Northwest China

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Abstract: It is of great significance to systematically analyze the characteristics of the regional grain supply and demand balance, reveal the influence mechanism of crop sustainable development, and put forward effective countermeasures to achieve the goal of food security. This paper aims at addressing the unique geographical characteristics of Northwest China and the current lack of research on its food security. This paper systematically analyzes the temporal and spatial variation characteristics of the regional grain production, consumption and food security level. The main factors affecting regional food security are examined, and we put forward effective suggestions to promote regional sustainable production. The results show that the average annual growth rate of grain production in Northwest China from 2000 to 2021 was 3.4%, and the years of increased grain production accounted for 77.3%. The main reason for the increase in grain production was the increase in yield per unit area (average annual growth of 2.8%), of which the rice yield was the largest, up to 7.3 t/ha. Maize and wheat accounted for 60.7% and 23.4% of the total grain production in the region, respectively. From the perspective of the regional structure, Inner Mongolia contributed the most to the grain production in the region, accounting for 33.5% of the total output. Xinjiang, Shanxi, Shaanxi, Gansu, Ningxia and Qinghai contributed 17.1%, 15.4%, 15.2%, 13.0%, 4.5% and 1.3%, respectively, to grain production. From the perspective of the dietary structure, the grain consumption pattern in Northwest China has gradually changed from raw grains to animal products, which has undoubtedly increased the regional demand for grain. At present, since the increase in output is greater than the demand for food, the food self-sufficiency rate in the region has increased from 0.81 to 1.28. Since the grain yield per unit area in Xinjiang and Ningxia has a relative advantage over other provinces, to achieve regional food security for a long time, moderately increasing the grain planting area in these two provinces will help to promote regional food security. In addition, as the grains produced in the region are mainly wheat and corn, the yield level of wheat and corn in Xinjiang and Qinghai has a comparative advantage within Northwest China. Therefore, moderately increasing the planting area of wheat and corn in Xinjiang and Qinghai is of great significance in ensuring regional food security. The research results can provide theoretical support for the realization of regional food security and provide a reference for other regions in the world, to better serve global food security.

Keywords: supply and demand balance; food security; grain production; spatial and temporal characteristics; limiting factors

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Citation: Liu, X.; Xu, Y. Analysis of Dynamic Changes and Main Obstacle Factors of Grain Supply and Demand Balance in Northwest China. *Sustainability* **2023**, *15*, 10835. https://doi.org/10.3390/su151410835

Academic Editor: Teodor Rusu

Received: 7 June 2023
Revised: 6 July 2023
Accepted: 7 July 2023
Published: 10 July 2023

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1. Introduction

Food security has always been a global problem affecting human survival and development. Food is the basic material condition for human survival and development. The problem of food security is related to the security and social stability of a country, the

construction of a harmonious society and the healthy and sustainable development of a country. According to the report 'World Food Security and Nutrition 2022', the number of people affected by hunger worldwide has increased to 828 million, an increase of approximately 140 million compared to three years ago [1,2]. This poses a huge challenge to the global sustainable development goal of zero hunger by 2030. As a populous country, China is the world's largest food producer and consumer [3]. Since 1979, China's grain output has increased from 270 million tons to 687 million tons in 2022, an increase of 1.54 times. Since 2004, China's grain production has achieved continuous growth for 19 years and made outstanding contributions to world food security. From 1979 to 2022, the average annual growth rate of China's total grain output was 2.25%, higher than the world average annual growth rate of 1.56% [4]. Today, China produces approximately 25% of the world's food, with approximately 9% of the world's arable land, and satisfies the dietary needs of 21% of the world's population, with a 'large country effect' [5,6]. This 'large country effect' is reflected in the fact that the dynamic changes in China's grain supply and demand have a huge impact on the stability of the world grain market [6]. Therefore, whether China achieves food security is of great significance to the global goal of food security.

Whether Northwest China achieves food security or exceeds the level of food security is of great significance in ensuring China's food security. With the rapid urbanization and industrialization of China, the area of arable land in economically developed regions such as Southern and Eastern China has been greatly reduced, making Northwest China (which is relatively backward and has always been dominated by agricultural production, with advantages in land, light and heat resources) increasingly important in ensuring national food security [7]. Northwest China produces 12% of China's grain, with approximately 10% of China's water resources and 15% of its grain cultivation area, which is of great significance in ensuring national food security. From 2000 to 2021, the region's grain output increased from 50.2 million tons to 99.8 million tons, with an increase of 98.9%, much higher than China's 47.7% increase over the same period. In 2021, the per capita grain output in Northwest China was 614.63 kg, higher than the national average of 483.40 kg. It is of great significance to explore the dynamics of food supply and demand balance changes in Northwest China and analyze the influencing factors affecting its sustainable development, to promote food security in this region and ensure China's food security in the long term.

Food security has been the highest priority of the international community and a central topic of academic development research [8]. Against the background of severe global food shortages, food security and agricultural sustainability have received great attention due to population growth and technological constraints, water shortages in the western and southern regions of developing Asia and unsuitable terrain [9]. By analyzing the factors affecting the sustainable development of agriculture, it is shown that water resources are the key factors affecting food security, especially in arid and semi-arid areas [7,10–13]. Therefore, many scholars have focused on how to improve the crop water use efficiency to address the issue of sustainable food production in arid and water-scarce regions. There is now a wealth of research findings; for example, studies suggest improved water-saving irrigation techniques such as subsurface drip irrigation [14], bubbled-root irrigation [15], deficit-regulating irrigation [16,17] and rainwater harvesting in furrows [18], which help to relieve pressure on regional water resources to better achieve regional food security. In addition, the use of precision agriculture [19] and rainfed smart agriculture techniques to vigorously develop rainfed agriculture [20] can effectively improve the efficiency of crops' use of precipitation, thereby reducing the amount of irrigation water required. Under the condition of water-saving irrigation technology, combination with biochar can further improve the water use efficiency and alleviate regional water resource pressure [21,22]. Intensive agriculture [23] and smart agriculture [24,25] were later proposed to reduce the amounts of water required by crops while maintaining food production. Thus, it is necessary to explore the coupling characteristics of water resources and food security, to reveal the mechanism of the impact of water resources on sustainable crop production and to propose effective response measures to promote sustainable crop production in

drylands [7,26]. In summary, the focus of many scholars regarding food security is how to improve the efficiency of water use by crops in order to relieve pressure on regional water resources, promote sustainable crop production and thus better achieve regional food security. However, scholars have not systematically explored the spatial and temporal characteristics of the food production and consumption demand, which are closely related to food security, and the factors that influence them. In order to realize regional and country-wide food security, it is of great significance to explore the influence mechanism of regional food security from the perspective of food supply and demand balance characteristics and put forward effective suggestions and measures. Obviously, there is still a lack of research in this area.

In view of the shortcomings of the current research, this paper takes Northwest China as the research area, based on quantifying the yield and consumption of food crops (rice, wheat, maize, beans and potatoes) in the region. The temporal and spatial variation characteristics of grain crop production, the consumption structure and the food security level in the region are systematically analyzed. The main influencing factors of regional grain production and consumption are explored, and the influence mechanism of each factor on the balance of the grain supply and demand in the region is revealed. Measures to effectively promote the sustainable production of regional food crops are put forward. The research results are of great significance in promoting the sustainable production of regional crops and ensuring food security in China and even the world.

2. Materials and Methods

2.1. Overview of the Study Area

Northwest China (73°40′–126°04′ E, 31°60′–53°23′ N) covers seven provinces (regions), namely Xinjiang, Qinghai, Gansu, Inner Mongolia, Ningxia, Shaanxi and Shanxi, and the land area accounts for approximately 46% of China's area (Figure 1). The region is rich in land resources, but its water resources are very scarce. As the most arid and ecologically fragile area in China [27], its water resources represent only 10% of the country [7]. The average annual precipitation in most areas is below 250 mm, but the evaporation is above 1000 mm and even more than 2000 mm [7]. With the rapid development of urbanization and the economy of Southern China, the importance of Northwest China, which has long been dominated by agricultural production, in ensuring national food security is rapidly increasing [7].

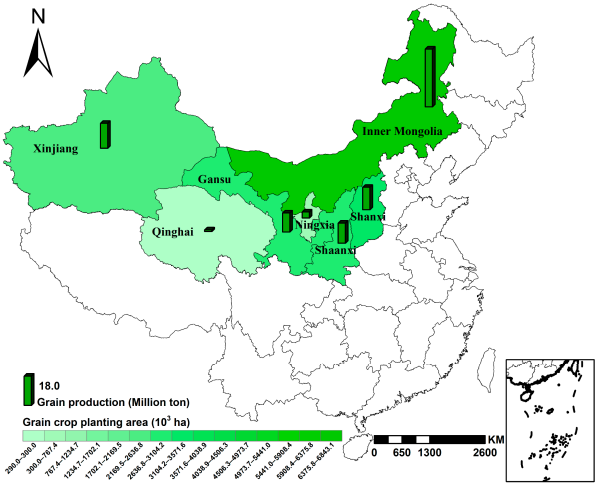

Figure 1. Overview of the study area.

2.2. Methods

(1) Food self-sufficiency rate calculation method.

$$w = G/D \times 100\% \quad (1)$$

where w represents the regional food self-sufficiency rate (%). G represents the total regional grain output (kg). D represents the regional food consumption demand (kg).

(2) Grain consumption demand calculation method.

In this paper, the calculation of grain consumption in Northwest China mainly involves the direct consumption of urban and rural residents, feed consumption, seed retention and loss consumption during transportation and storage. Direct consumption refers to the amount of grain directly consumed by residents. Feed consumption mainly refers to the amount of grain needed to produce animal products. Animal products mainly include pork, beef, mutton, edible oil, poultry, eggs, seafood products and milk. In addition, there is corresponding invalid waste during the grain growth period, harvest period, transportation and storage period. Furthermore, to ensure an effective cycle of sustainable food production, a certain number of high-quality food seeds need to be retained as seeds for the next season.

$$G_d = P_u \cdot d_u + P_r \cdot d_r \tag{2}$$

where G_d represents direct grain consumption (kg). P_u indicates the size of the urban population. P_r represents the rural population. d_u and d_r represent the per capita direct grain consumption of urban and rural residents, respectively.

$$G_c = P_u \cdot \sum_{i=1}^{8} U_i \cdot a_i + P_r \cdot \sum_{i=1}^{8} R_i \cdot a_i \tag{3}$$

where G_c represents the amount of food consumed for feed production (kg). U_i and R_i represent the amount of food i consumed per capita by urban and rural residents, where i represents the following: 1 = pork, 2 = beef, 3 = mutton, 4 = cooking oil, 5 = poultry, 6 = eggs, 7 = seafood products and 8 = milk. a_i represents the conversion ratio of the i-th food and grain, where i = 1, 2, . . . ,8 correspond to the conversion rate of grain, which is 4.6, 4.1, 4.1, 4.6, 3.2, 3.6, 2.0 and 0.8 [28].

$$D = G_d + G_c + G_{seed} + G_{loss} \tag{4}$$

where G_{seed} and G_{loss}, respectively, indicate the number of seeds stored by farmers in the current year and the amount of loss during grain transportation and storage, and we set the amount of food waste and retained seeds as 5% of the total regional grain output in that year based on the actual production [29].

2.3. Data Sources

Agricultural production data mainly include data on the output and planting areas of grain crops (rice, wheat, maize, soybeans and potatoes) in various provinces in Northwest China. The consumption data mainly include the per capita food consumption (including direct edible grain, livestock and poultry meat, cooking oil, eggs, seafood products and milk, etc.) in various provinces in Northwest China. Population data mainly include the number of urban and rural residents. These data are derived from the China Statistical Yearbook, China Rural Statistical Yearbook, China Northwest Provincial Statistical Yearbook, China Environmental Statistical Yearbook and China Agricultural Statistical Yearbook.

3. Results

3.1. Temporal and Spatial Variation Characteristics of Grain Production

3.1.1. Dynamic Changes in Grain Yield

Grain production in Northwest China showed a trend of fluctuating increases from 2000 to 2021 (Figure 2). During the study period, the average annual grain yield growth rate was 2.40 $\times$ 10^6 tons, with an average annual growth rate of 3.4%, where the years with increased grain yields accounted for 77.3%. Grain production increased from 5.02 $\times$ 10^7 tons in 2000 to 1.02 $\times$ 10^8 tons in 2021, with an increase of 103.8%. The average annual output

was 7.59 × 10^7 tons, and the highest output occurred in 2021, which was 1.4 times the average annual output. The minimum yield occurred in 2001, which was 0.6 times the multi-year average. The year with the largest grain production yielded 1.8 times that of the year with the least. The grain yield was low in 2000–2003. At this stage, the average grain yield in Northwest China was 5.30 × 10^7 tons, with an average annual increase of 9.0 × 10^5 tons. The period of 2004–2007 was the recovery stage of grain production. The average grain yield at this stage reached 5.97 × 10^7 tons, and the average annual yield increase was 1.3 × 10^6 tons, which was 1.4 times that of the first stage. The period of 2008–2021 showed a rapid grain yield increase. At this stage, the grain output increased from 6.57 × 10^7 tons to 1.02 × 10^8 tons, and the average annual output reached 8.73 × 10^7 tons, with an average annual increase of 2.6 × 10^6 tons. The increase was 2.9 times and 2.0 times that of the first two stages, respectively.

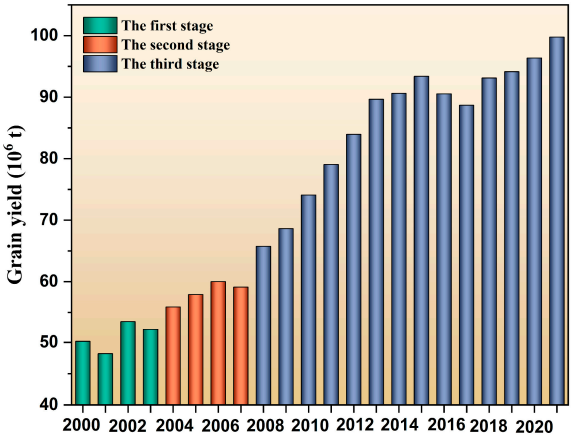

Figure 2. Changes in grain production in Northwest China from 2000 to 2021.

Considering the limitations of mathematical statistics, they cannot systematically reflect the inter-annual trends of grain production in Northwest China. The method of difference product curve analysis was introduced to systematically analyze the inter-annual variation characteristics of grain production in Northwest China (Figure 3). The period from 2000 to 2010 saw a continuous reduction ($k < 0$), with an average output of 5.87 × 10^7 tons, lower than the annual average grain output in Northwest China (7.59 × 10^7 tons). This means that although the inter-annual changes in food production show a fluctuating upward trend (Figure 2), the increase in food production is slow relative to the multi-year average, food production is still at a low level and production has not yet increased substantially. On the contrary, compared with the research period, 2011–2021 was a period with a continuous increase in production, with average annual grain production of 9.18 × 10^7 tons, which was 20.9% higher than the average grain production for many years. This shows, to a certain extent, that grain production during this period was already at a relatively high level.

In terms of grain structure, the grain yield in Northwest China is mainly composed of maize and wheat (Figure 4). From 2000 to 2021, maize and wheat accounted for 60.7% and 23.4% of the total output in Northwest China, respectively. The other three grain crops, rice, soybean and potato, accounted for 3.9%, 4.2% and 7.8%, respectively. The largest yield of maize was 15.5 times that of rice. In terms of time series, all five grain crops showed upward volatility over time. The average annual growth rates of rice, wheat, maize, soybean and potato were 0.1%, 0.7%, 6.0%, 1.2% and 1.0%, respectively. Rice showed a downward trend from 2000 to 2007 and then an upward trend, but none of them were significant. Wheat showed a decreasing trend in volatility from 2000 to 2008, but this was not significant. From 2009 to 2011, there was an upward trend, which was not significant. There was a significant increase from 2012 to 2021 ($p < 0.05$). For maize, there was a year-on-year increase during

the study period, but this trend was not significant from 2000 to 2002, and it showed a significant increase from 2003 to 2021 ($p < 0.01$).

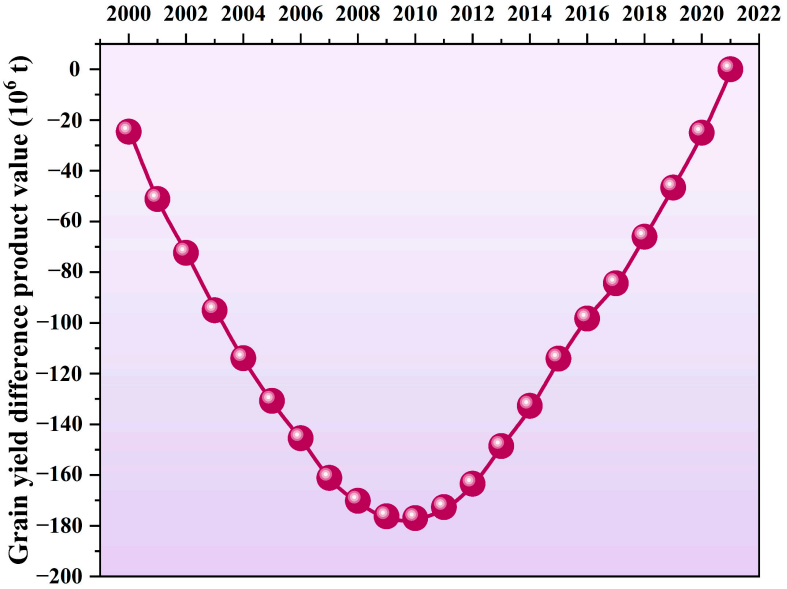

Figure 3. The difference product curve of grain production in Northwest China from 2000 to 2021. Note: The difference product curve is the cumulative departure curve, which is obtained by the accumulation of anomalies. The calculation method is $k = \sum_{t=1}^{n} (q_t - \overline{q})$, where k represents the cumulative anomaly value of each year in Northwest China, 10^6 tons. q_t represents the grain output of the northwestern region in the t-th year, 10^6 tons. $\overline{q}$ represents the average grain production in the northwestern region from 2000 to 2021, 10^6 tons.

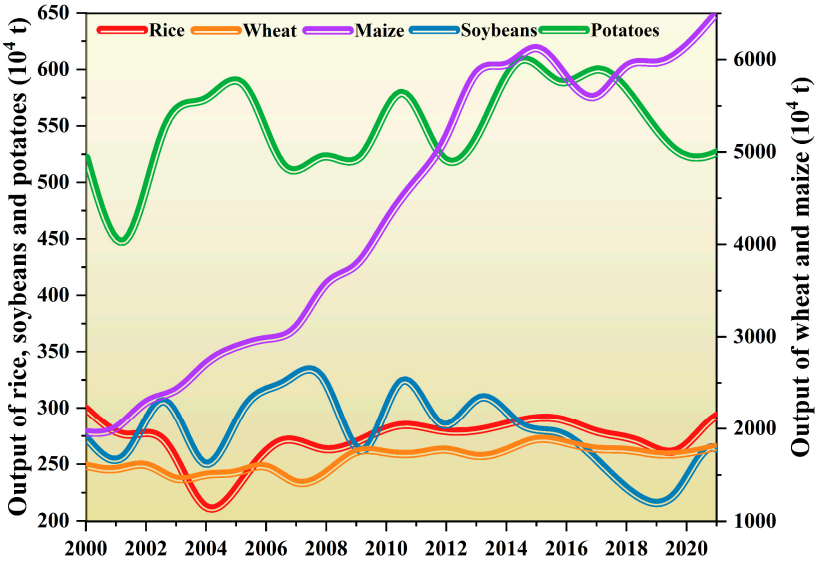

Figure 4. The structure of grain output in Northwest China from 2000 to 2021.

Analyzing from the perspective of time and space, the grain output of each province in Northwest China showed different degrees of difference. The average grain output of Inner Mongolia from 2000 to 2021 contributed the most to the grain output in Northwest China, accounting for 33.5% of the total output (Figure 5). This was followed by Xinjiang, Shanxi, Shaanxi, Gansu, Ningxia and Qinghai, which contributed 17.1%, 15.4%, 15.2%, 13.0%, 4.5% and 1.3% of the grain output in Northwest China, respectively. It can be seen that the key province to ensure food security in Northwest China is Inner Mongolia.

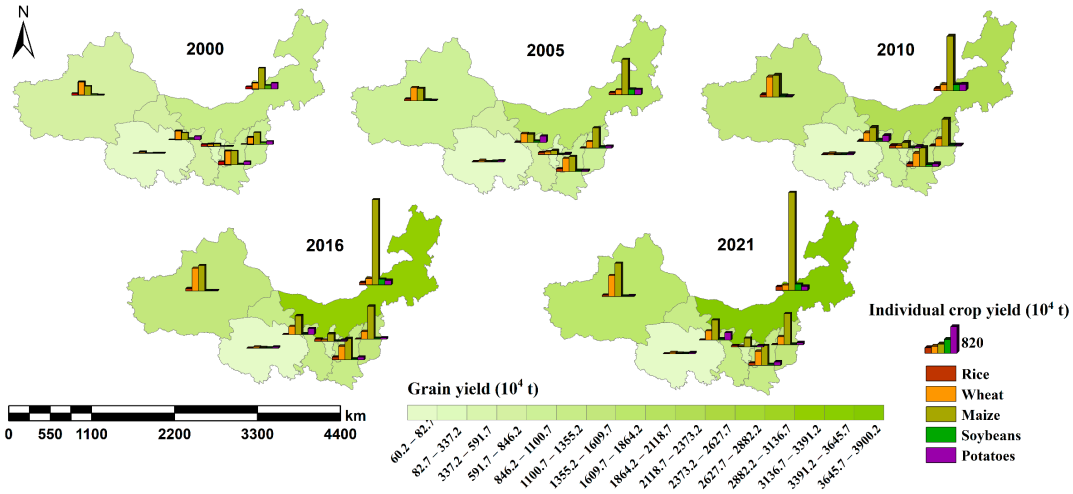

Figure 5. The output of grain crops in various provinces from 2000 to 2021.

From 2000 to 2021, the largest annual increase in grain output among all provinces was in Inner Mongolia (5.5%), followed by Xinjiang (4.3%). Inner Mongolia saw the largest annual increase in maize production (7.9%). Soybean followed, at 4.9%. The smallest annual increase was in potato (−0.1%). Inner Mongolia's maize production contributed the most to the total grain production, reaching 76.5%, while wheat, soybean and potato contributed less, at 7.0%, 6.8% and 6.7%, respectively. It can be seen that the crop planting structure in Inner Mongolia is relatively singular, comprising mainly maize. In Shaanxi, maize, soybean and potato increased by 2.1%, 1.9% and 2.4% per year, respectively. Rice and wheat showed a trend of decreasing fluctuations over time, with average annual decreases of 0.9% and 0.2%, respectively. With the slight decline in wheat production, maize and wheat are the two major crops that guarantee Shaanxi's grain production. Their contribution rates to Shaanxi's grain output were 46.7% and 35.5%, respectively. For Xinjiang, from 2000 to 2021, rice, wheat, maize and potato all showed an increasing trend year by year, with average annual growth rates of 1.8%, 4.5%, 7.6% and 10.5%, respectively. The average annual rate of change in soybean production showed a decreasing trend, which was 4.0%. The grain composition in Xinjiang is mainly composed of wheat and maize, and the output of these two grain crops accounted for 41.5% and 48.9% of the total grain output, respectively. During the study period, in Shanxi, maize and rice had the largest growth rates among the five food crops, with an average annual growth rate of 7.6% and 4.0%, respectively. Soybean showed a trend of decreasing volatility, with an average annual decrease of 2.2%. Shanxi's grain structure is relatively simple, mainly maize, which accounts for 66.3% of the total output. From 2000 to 2021, the average annual variation in rice and bean production in Gansu was −3.9% and −2.6%, respectively. The other three grain crops showed an upward trend, especially maize, which increased by an average of 7.1% per year. Gansu's grain production structure is relatively diversified, mainly composed of wheat, maize and potato, which account for 29.1%, 39.5% and 19.4% of the total output, respectively. The average annual grain output of rice, wheat, maize and potato in Ningxia accounted for 19.3%, 20.3%, 47.0% and 10.1% of the total output, respectively. Qinghai's grain output structure is dominated by wheat and potatoes, accounting for 40.8% and 30.2% of the total grain output, respectively. Maize yields increased the most during the study period, at 27.5%. The diversity of the grain production structures among provinces in Northwest China has ensured food security in the region.

3.1.2. Temporal and Spatial Variation Characteristics of Grain Yield Per Unit Area

From 2000 to 2021, the grain yield per unit area in Northwest China showed a fluctuating upward trend, with an average annual increase of 2.8% (Figure 6). Through the M-K trend test analysis, it could be seen that, from 2000 to 2003, the growth in the grain yield

per unit area in Northwest China was at a non-significant level. The grain yield per unit area increased significantly from 2004 to 2021 ($p < 0.01$). From a statistical point of view, the level of the grain yield per unit area in Northwest China showed a significant linear relationship with time ($p < 0.01$). For every additional year during the study period, the level of the grain yield per unit area will increase by 0.1 t/ha.

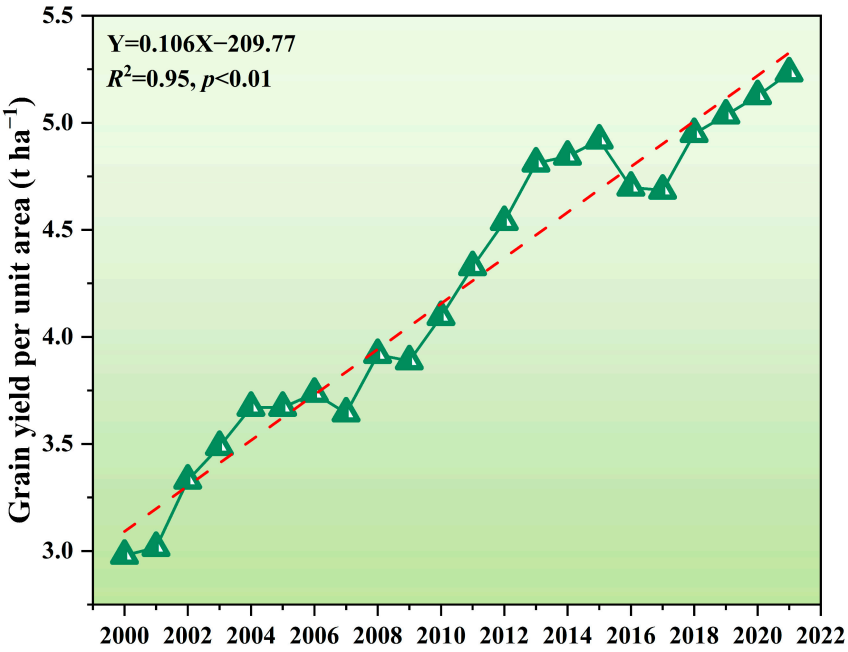

Figure 6. Changes in grain yield per unit area in Northwest China from 2000 to 2021.

From the perspective of the crop structure, the yield per unit area of the five grain crops in Northwest China showed a fluctuating increase trend from 2000 to 2021 (Figure 7). Among the five grain crops, rice had the largest average yield of 7.3 t/ha. This was followed by maize, wheat, potato and soybean, with yields of 5.8, 3.7, 3.0 and 1.5 t/ha, respectively. In terms of time series, the rice yield per unit area showed a fluctuating increase trend during the study period, with an average annual increase of 4.7%. During 2003–2005, the rice yield showed a downward trend but did not break the confidence interval, so the downward trend was not significant. In other periods, the rice yield showed an upward trend, especially in 2010–2021 ($p < 0.05$). It is worth noting that the rice yield per unit area mutated in 2007, and the yield per unit area after the mutation was 1.2 tons higher than before, with a relative increase of 18.7%. The yield level of wheat showed a significant increasing trend over time ($p < 0.05$), with an average annual increase of 2.5%. The M-K trend test analysis showed that the rising trend in the yield per unit area did not reach a significant level from 2000 to 2003, while the other stages showed a significant upward trend ($p < 0.05$). As an important grain, the yield of maize showed a significant upward trend during the study period ($p < 0.05$), with an average annual increase of 1.7%. The improvement in the grain yield per unit area in Northwest China has greatly improved the level of food security in the region.

From the perspective of time and space, the dynamic changes in the grain crop yield level in Northwest China were analyzed, which showed that each grain crop had relative comparative advantages in space. Xinjiang has the highest grain yield level of 6.1 t/ha, which is 1.5 times that of Northwest China (Figure 8). Ningxia also has a higher yield level than the region, which is 4.3% higher than the regional average. This shows that Xinjiang and Ningxia have comparative advantages in grain yields compared with Shanxi, Shaanxi, Gansu, Inner Mongolia and Qinghai. A moderate increase in grain planting in Xinjiang and Ningxia will help to increase grain production, thereby better ensuring regional food security. From the perspective of time series, the grain yield per unit area of Inner Mongolia,

Ningxia, Shanxi, Xinjiang, Gansu and Shaanxi showed a significant upward trend ($p < 0.01$) from 2000 to 2021, with an average annual increase of 3.6%, 3.3%, 3.4% and 1.4%, 3.2% and 2.2%, respectively.

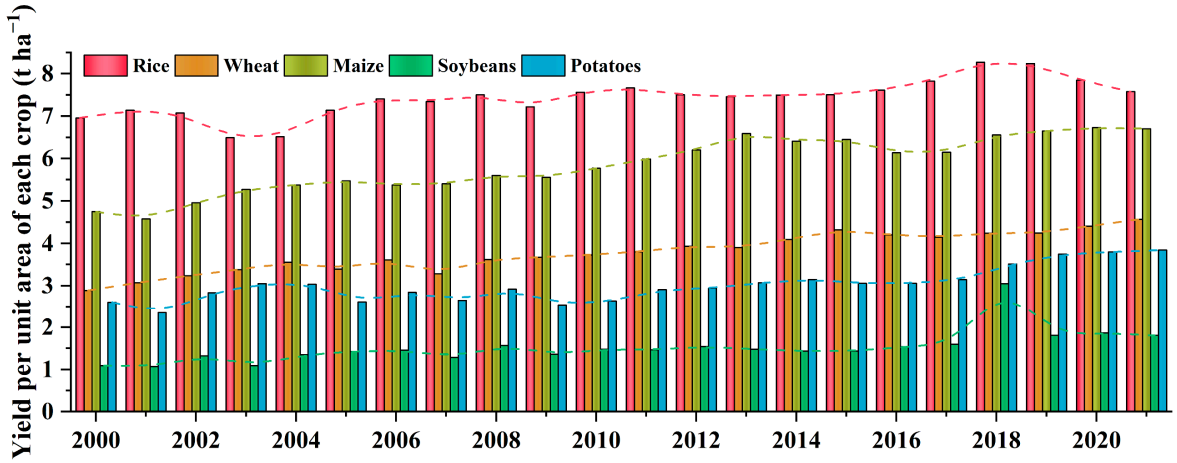

Figure 7. Changes in grain yield per crop in Northwest China from 2000 to 2021.

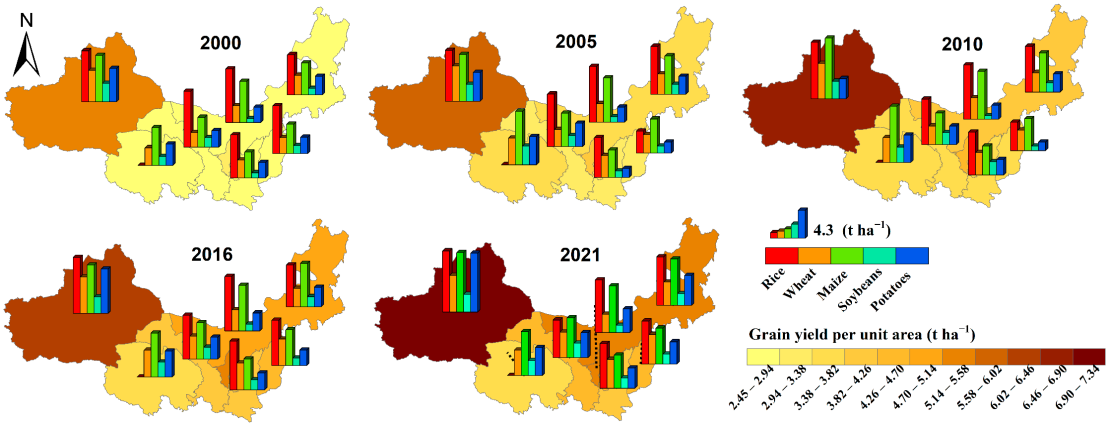

Figure 8. Spatio-temporal trends of grain yield per crop in Northwest China from 2000 to 2021.

From the perspective of the grain crop structure, the yield per unit area of the same grain crop also has relative comparative advantages among different regions. For rice, Ningxia had the highest yield level between 2000 and 2021, at 8.3 t/ha. It was followed by Xinjiang, Gansu, Inner Mongolia, Shaanxi and Shanxi. Among them, Ningxia's value was 1.7 times that of Shanxi. There were three provinces with a higher than average rice yield per unit area in Northwest China, namely Ningxia, Xinjiang and Gansu. The rice yield levels in these three provinces were 1.2, 1.2 and 1.1 times the regional average, respectively. This shows that these three provinces have a relatively high rice yield level compared with other provinces, which means that they have relative comparative advantages. For wheat, Xinjiang has a higher yield per unit area than other provinces, at 5.4 t/ha. It is followed by Qinghai, Shaanxi, Shanxi, Ningxia, Inner Mongolia and Gansu. The yield level of wheat in the largest province was 85.7% higher than that in the smallest province, indicating that wheat in Xinjiang has a greater comparative advantage than that in Gansu. The provinces with higher average wheat yields in Northwest China were Xinjiang and Qinghai. The wheat yields in these two provinces were 51.6% and 7.8% higher than the regional average, respectively. This shows that wheat in Xinjiang and Qinghai has a relatively high comparative advantage in Northwest China, and appropriately increasing the planting area of wheat in these two provinces (especially Xinjiang) has played an important role in increasing their grain production. For corn, the province with the highest

yield per unit area from 2000 to 2021 was Xinjiang, followed by Qinghai, Ningxia, Inner Mongolia, Shanxi, Gansu and Shaanxi. Among them, Xinjiang, Qinghai and Ningxia were the provinces with higher average yields of maize in Northwest China. The yields of maize in these three provinces were 33.8%, 18.7% and 15.6% higher than the average in Northwest China, respectively. In summary, for the three most important grain crops, rice, wheat and maize, the provinces with comparative advantages in rice production in Northwest China are Ningxia, Xinjiang and Gansu. The provinces with comparative advantages in wheat production are Xinjiang and Qinghai. Similarly, the provinces with relative comparative advantages in maize production are Xinjiang, Qinghai and Ningxia. Therefore, moderately expanding the corresponding crop planting areas in these provinces with comparative advantages will inevitably help to increase grain production and better ensure regional food security.

3.2. Analysis of Grain Consumption Demand Characteristics

From 2000 to 2021, grain consumption in Northwest China showed a significant linear increase ($p < 0.05$), with an average annual increase of 1.1% (Figure 9). Through the analysis of the M-K trend test, it can be seen that the increasing trend of grain consumption in Northwest China from 2000 to 2012 was not significant, and it showed a significant increase trend from 2013 to 2021 ($p < 0.01$). The average grain consumption in these two stages was 6.25×10^7 tons and 6.75×10^7 tons, respectively. From a statistical point of view, with time, for each additional year, the food consumption in the Northwest region will increase by 4.0×10^5 tons. During the study period, the average annual grain consumption reached 6.45×10^7 tons, and the grain consumption in 2021 was 20.8% and 25.2% higher than the annual average and the value for 2000, respectively. The increase in residents' demand for food year by year will inevitably bring greater challenges in ensuring regional food security.

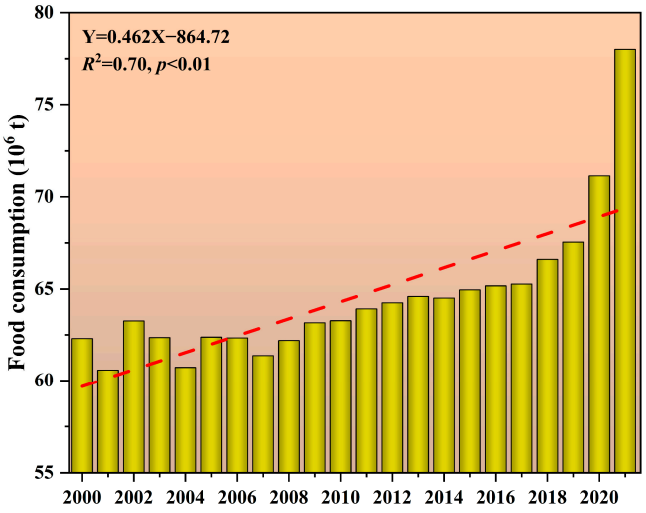

Figure 9. The dynamic changes in grain consumption in Northwest China from 2000 to 2021.

From the perspective of the dietary structure, the grain consumption structure in Northwest China has gradually changed from raw grains to animal products. From 2000 to 2021, residents' direct food consumption decreased by 28.3%, with an average annual decrease of 1.5% (Figure 10). The indirect consumption of cooking oil, pork, beef and lamb, poultry, seafood products, eggs and milk has shown a trend of increasing year by year, with an average annual growth rate of 1.1%, 2.7%, 6.2%, 6.7%, 4.3%, 3.6% and 6.1%, respectively. Among them, the largest increase in dietary structure was seen for poultry and pork, and the consumption of these two foods increased from 3.3% and 19.6% to 7.7% and 23.9%, respectively, from 2000 to 2021. It can be also be inferred from the changing trends in the consumption of these animal products during the research period that the consumption

demand for them in Northwest China will further increase in the future. The production of these animal products requires more grain, which will increase the residents' demand for grain, which in turn will pose greater challenges to food security in Northwest China [7].

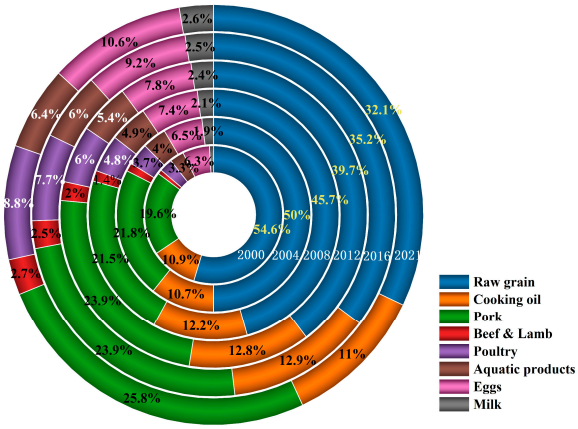

Figure 10. The structure of grain consumption in Northwest China from 2000 to 2021.

3.3. Analysis of Food Self-Sufficiency Rate Characteristics

Combined with the dynamic change trends of grain yields in Northwest China (Figure 2), the food self-sufficiency rate in Northwest China gradually transitioned from the risk stage to the food security stage (Figure 11). If further divided, the food self-sufficiency rate in Northwest China was at a risk stage (food self-sufficiency was less than 95% [29,30]) from 2000 to 2005, and the average food self-sufficiency rate was 85.5%. From 2006 to 2007, grain production was self-sufficient (food self-sufficiency rate was at 95–100% [29,30]), and the average self-sufficiency rate was 96.3%. The period from 2008 to 2021 saw the complete self-sufficiency of grain (food self-sufficiency rate was greater than 100% [29]), with a multi-year average of 130.4%. The gradual increase in the food self-sufficiency rate in Northwest China indicates its important role in ensuring China's food security.

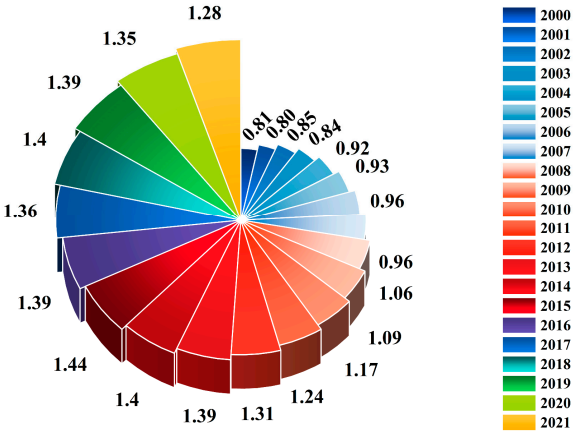

Figure 11. The dynamic changes in the food self-sufficiency rate in Northwest China from 2000 to 2021.

4. Discussion

4.1. Influencing Factors of Grain Yield

4.1.1. The Effect of Crop Planting Types between Regions on Grain Yield

Grain production is determined by the planting area and the grain output per unit area. By analyzing the correlation between grain production, the planting area and the grain production per unit area, it can be seen that the three showed a significant positive correlation, especially the production per unit area, with a correlation coefficient of 0.98

(Table 1). This shows that the increase in grain output was mainly due to the increase in grain output per unit area. However, the goal of increasing grain production can also be achieved by expanding the cultivated land area, considering that the per capita grain sown area in Northwest China is much higher than the Chinese average. With the deterioration of the ecology in Northwest China, urbanization and increased population aging, the quantity of cultivated land is decreasing and the quality is declining [7,31–33]. A decline in the quality of cultivated land reduces the ecological function of cultivated land, and it cannot maintain the ecological balance of the region, which is mainly caused by the decline in the soil organic matter content in cultivated land [34,35]. In addition, in the process of using natural resources to develop the economy, due to the problems of overexploitation and irrational utilization, scientific methods and means are not paid attention in production, which will also lead to the ecological environment of food cultivation becoming increasingly fragile [36,37]. Farmers have applied chemical inputs such as fertilizers, pesticides and herbicides in large quantities and in an uncontrolled manner for a long time, causing large areas of cultivated land to suffer erosion and pollution to varying degrees [6,38]. At present, the fertilizer application amount is as high as 400 kg/ha, far exceeding the safety limit of 225 kg/ha in developed countries [39]. All these have caused the serious degradation and destruction of cultivated land resources, so that the extent of soil erosion, desertification and cultivated land pollution continues to expand, disrupt the balance of the ecosystem and reduce the quality of cultivated land [40]. This also means that the grain sowing area in the arid northwestern region of China cannot be increased by expanding the cultivated land area, and thus the goal of increasing grain production cannot be achieved. Therefore, regarding the regional characteristics, it is particularly important to focus on improving the quality of regional arable land and increasing the grain yield to promote regional food security. By analyzing the grain yield per unit area in Northwest China and the average level in China, it can be seen that the grain yield per unit area in the study area is lower than that in China (4.7 t/ha in Northwest China and 5.5 t/ha in China in 2021). There is still much room for development to increase grain production by increasing the level of the grain yield per unit area in Northwest China. Therefore, efforts to increase grain production in the northwestern region should focus on how to increase the grain production per unit area.

Table 1. Correlation between grain production, sown area and yield per unit area in Northwest China.

Output (10^4 t)	Planting Area (10^3 ha)	Yield Per Unit Area (t/ha)
Grain crops	0.88 **	0.98 **
Rice	0.73 **	0.49 *
Wheat	0.28	0.78 **
Maize	0.99 **	0.97 **
Soybean	0.39	0.28
Potato	0.20	0.65 **

Note: Significant differences * and ** indicate $p < 0.05$ and $p < 0.01$, respectively. Nonparametric correlation analysis was performed using Spearman.

How can we increase the grain output per unit area in Northwest China? For arid Northwest China, water resources and the cultivated land quality are the main factors restricting its grain production potential. Therefore, in order to increase the food production per unit area, it is necessary to increase the efficiency of the crop use of water resources. At the same time, we must improve the quality of cultivated land. First, it is necessary to improve the technical and management levels of agricultural management [41,42] and improve the efficiency of the water use of food crops by increasing the construction of farmland water infrastructure and promoting water-saving irrigation technologies (such as drip irrigation, sprinkler irrigation and deficit irrigation) [43,44]. From a genetic point of view, it is possible to breed high-yielding and superior crop varieties, which in turn will lead to higher grain yields [45]. We can also strengthen the application of intelligent rainwater agricultural technology to better improve the efficiency of precipitation use [46,47]. Finally,

according to the characteristics of each region, the planting structures of food crops should be adjusted in a targeted manner to give full play to the relative comparative advantages and absolute comparative advantages between regions and within regions, thereby maximizing the water use efficiency of crops [48]. Moderately increasing the investment in agricultural productive materials (fertilizers, pesticides and agricultural films, etc.) is also a good choice to increase the grain yield per unit area. However, the implementation of these measures requires us to fully consider the fragile ecological environment of the region, and it is necessary to achieve the goal of increasing grain yields through the promotion of integrated water and fertilizer technology on the basis of not impacting ecological security [49–51]. Through these measures, it is expected to increase regional grain production without expanding the crop planting area, so as to better ensure food security.

Regarding the structure of the grain yield, the grain yield showed a strong positive correlation with maize and wheat, with correlation coefficients of 0.99 and 0.77 ($p < 0.05$), respectively (Figure 12). Further analysis of the correlation between the maize and wheat yields and the sown area and unit area yield showed that the maize yield was affected by both the sown area and unit area yield, and the correlation reached a significant level ($p < 0.01$, Table 1). The sown area of maize has a greater impact on its yield than the yield per unit area. For wheat, its yield was significantly affected by the yield per unit area ($p < 0.01$), but the sown area had no significant impact on its yield. Therefore, based on the lack of expansion potential of arable land, increasing the yield per unit area (especially corn and wheat) is the key to ensuring food security. In 2021, the yield per unit area of wheat in Northwest China was 0.8 times that of China's average level, indicating that it still has great potential for development. However, the yield per unit area of maize in Northwest China is close to the national average level, and it is difficult to further increase the yield per unit area. Nonetheless, maize has its advantages, such as strong drought tolerance and less artificial input during the entire growth period. These advantages are beneficial for the arid northwestern region and the background conditions of the acceleration of urbanization and population aging, aiding farmers in Northwest China [52]. Therefore, according to the characteristics and development potential of different crops in Northwest China, measures should be taken to improve the crop production potential and adjust the planting structure to improve the grain output in the region and better ensure regional food security.

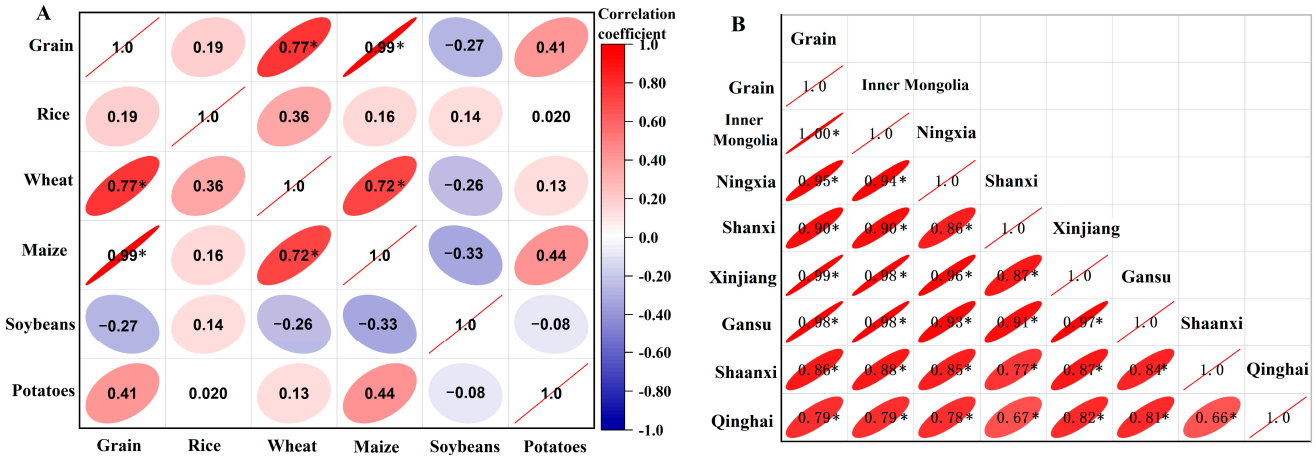

Figure 12. Correlation between grain output, crop types and regional output in Northwest China. (**A**) represents the correlation characteristics among crop yields in Northwest China. (**B**) represents the correlation characteristics between grain production and total regional production for each province in Northwest China. Significant differences * indicate $p < 0.05$.

4.1.2. The Impact of National Policies on Grain Production

The orientation of national policies determines the enthusiasm of farmers to engage in agricultural production. As shown in Figure 2, the main reasons for the low grain

yields in the first phase are as follows. (1) In the process of adjusting the agricultural planting structure, China reduced the area of grain crops planted to expand cash crops [53]. From 2000 to 2003, the planting area of grain crops in Northwest China decreased by 11.3%. (2) The process of urbanization is increasing, and the implementation of the western development strategy and the 'South-to-North Water Diversion' water resource protection project, coupled with the long-term distortion of grain prices, etc., have caused farmers to be in a negative state of grain production [6,7]. This has directly affected the output of grain in the region. (3) Due to the unreasonable adjustment of the agricultural planting structure, the government has realized that there is still a major threat to the country's food security. The Chinese government has promulgated a series of agricultural protection policies since 2003. For example, the 'Opinions of the CPC Central Committee and the State Council on Several Policies to Promote Farmers' Income Increase', issued and put into effect in December 2003, pointed out that it is necessary to strengthen the support for the development of the grain industry in major grain-producing areas, to increase the economic income of farmers engaged in grain production [54]. It also emphasizes strengthening the breeding of excellent grain crop varieties, the construction of disease prevention and pest prevention projects, continuing to increase the effective irrigation areas of crops and the construction of large, medium and small water conservancy facilities on farmland. The implementation of this preferential policy and the Chinese government's corn inventory policy to purchase corn at a protective price have greatly increased farmers' efforts to grow corn (Figure 3). In addition, compared with other food crops, corn does not require excessive farm management from sowing to harvesting, which can greatly free up agricultural labor to engage in other tasks to obtain more income [55]. This is the main reason that farmers tend to grow corn, which in turn leads to the dominance of maize production in the northwestern region (Figure 3). Moreover, 'the Opinions on the Implementation of the Opinions of the Central Committee of the Communist Party of China and the State Council on Further Strengthening Rural Work and Improving Comprehensive Agricultural Production Capacity', issued in 2005, clearly stated that the 'two reductions and three subsidies' policies should be conscientiously implemented [56]. Specifically, this includes agricultural tax exemptions and exemptions, direct subsidies to farmers engaged in agricultural production, subsidies for the purchase of excellent crop varieties and subsidies for the purchase of agricultural machinery. The implementation of these policies has greatly stimulated and mobilized farmers to engage in food production [31]. With the implementation of a series of policies to benefit farmers and the intensification of basic farmland construction and land reclamation and development, the amount of cultivated land in Northwest China, which originally had an advantage in land area, has gradually increased [6]. These factors re-incentivize farmers to engage in agricultural production and increase their inputs in agricultural productive materials (such as chemical fertilizers, pesticides and agricultural films, etc.). This has led to a steady increase in grain production during this period (Figure 2). With the support of the national policy benefiting farmers, agricultural technologies are constantly improving; with high-efficiency water-saving methods, fertilization technology and other large-scale measures, the land productivity has been greatly improved, which has also led to the transformation of the agricultural production mode in Northwest China from extensive to economizing green agriculture [31].

4.2. Analysis of Factors Affecting Grain Consumption

An understanding of the factors influencing regional food consumption is essential to ensure regional food security. As the world's most populous developing country, China has seen rapid economic development since the reform and opening up. Residents' income has been increasing since the mid-1980s, the problem of food and clothing for residents has been essentially solved and the dietary structure has begun to transition to a moderately prosperous level, which is mainly manifested in a significant decrease in the number of food rations for direct consumption, while the consumption of animal foods has increased

significantly (Figure 10). The early 21st century is a key stage in China's economic development and urbanization; China has built a moderately prosperous society and expects to reach the level of a moderately developed country by 2030. In 2021, China's urbanization rate was 64.7%, which is in the middle stage of accelerated development, with an urbanization rate of 30–70%, and it is expected to reach approximately 70% in 2035. This means that the per capita income and consumption level of Chinese citizens will be significantly increased, and the dietary structure will be significantly improved [31]. Further analysis of the population structure showed that urban and rural residents have different consumption demands for food [57,58]. As far as Northwest China is concerned, the per capita food consumption of urban residents has increased year by year from 2000 to 2021, increasing by 16.1% during the study period, and will continue to increase in the future. The per capita grain consumption of rural residents shows a trend of decreasing year by year, with an average annual decrease of 1.0%. In 2021, it decreased by 15.1% compared with 2000. The per capita grain consumption of urban residents has increased year by year, while the per capita grain consumption of rural residents has decreased year by year. The main reasons are as follows. (1) With the rapid development of urbanization, a large number of rural young adults have been transferred to the city on a large scale, which has greatly increased the per capita food consumption in urban areas [31]. In contrast, the rural population shows the phenomenon of '99·38·61 villages' (the elderly, women and children), which also greatly reduces the per capita food consumption in rural areas [7,31,59]. (2) The dietary structure is different. Urban residents are more inclined to consume animal products, and, on the basis of providing the same calories, animal products need more food input [7,31,58]. Globally, with the exception of a few countries, highly urbanized countries consume more animal protein than the world average in the form of pork, poultry, beef and dairy [60]. This shows that with the increase in the urbanization level in Northwest China, the demand for animal products will continue to grow. Residents in rural areas mainly consume food on their own farms and have a relatively low demand for animal products [61]. This also determines the low per capita food consumption of rural residents to a certain extent. However, as urbanization levels increase, large numbers of rural young people are moving to cities and the urban population is increasing significantly [7]. This will significantly increase the food consumption demand in Northwest China, posing an even greater challenge to future food security.

5. Conclusions

Based on quantifying the yield and consumption of grain crops (rice, wheat, maize, soybeans and potatoes) in Northwest China, this paper systematically analyzed the temporal and spatial variation characteristics of crop production, the consumption structure and the food security level in Northwest China. The dynamics and limiting factors of regional food supply and demand balance changes are revealed, and suggestions and measures are put forward to effectively promote the sustainable production of regional food crops. The main conclusions reached are as follows.

During the study period, grain production in Northwest China showed a good development trend. The increase in grain yield levels is the main factor leading to the increase in regional grain production. There are obvious differences in grain yield per unit area among provinces in Northwest China, among which Xinjiang and Ningxia have comparative advantages. Therefore, moderately increasing the area of grain planting in the region will help to improve the level of food security in Northwest China. From the perspective of the grain structure, the main contributing crops are wheat and maize. Xinjiang and Qinghai have a comparative advantage in terms of the wheat yield per unit area. The yield per unit area of maize in Xinjiang, Qinghai and Ningxia also shows a comparative advantage. Therefore, moderately increasing the planting area of wheat and corn in Xinjiang and Qinghai is of great significance in ensuring regional food security.

The dietary structure in Northwest China is undergoing major changes. Residents' demand for food is gradually shifting from rations to animal products. Under the same

calorie supply conditions, animal products require more raw grains. This will undoubtedly increase the consumption demand of residents for grain. Fortunately, the current increase in regional grain production is greater than the demand for grain consumption, which also promotes a gradual improvement in food security. It is worth noting that as the Chinese government attaches great importance to the ecological environment and limits the input of major agricultural chemicals in food production, this will inevitably bring new challenges to food security in the future.

Focusing on the new challenges of regional food security in the future, this paper systematically analyzed the influencing factors of regional grain production and the food consumption demand; combined with regional characteristics, it puts forward in detail effective measures to promote sustainable regional food production and food security. The results of this study can provide a reference for other similar regions around the world, to better serve global food security.

Author Contributions: X.L. and Y.X. conceived the central idea. X.L. and Y.X. collected the data and performed the calculations. X.L. created all figures. X.L. wrote the first draft. X.L. and Y.X. corrected the English language for the paper. All authors contributed to the analysis and developed the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the Fundamental Research Program of Shanxi Province (Free Exploration Category) (202103021223261; 202203021212415), Shanxi Normal University Fund (Shanxi Province High-Quality Development Major Issues Research Project) (GZLFZ2313), Shanxi Agricultural University Doctoral Fund Project (2021BQ46) and National Key Research and Development Program of China (2021YFD1901101-1).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wijerathna-Yapa, A.; Pathirana, R. Sustainable Agro-Food Systems for Addressing Climate Change and Food Security. *Agriculture* **2022**, *12*, 1554. [CrossRef]
2. Hou, D. Sustainable Soil Management for Food Security. *Soil Use Manag.* **2023**, *39*, 1–7. [CrossRef]
3. Shaikh, M.A.; Hadjikakou, M.; Bryan, B.A. Shared responsibility for global water stress from agri-food production and consumption and opportunities for mitigation. *J. Clean. Prod.* **2022**, *379*, 134628. [CrossRef]
4. Wang, H. Food Production: A 60-Year Review and 20-Year Outlook. In *China's Food Security: Strategies and Countermeasures*; Springer: Berlin/Heidelberg, Germany, 2023; pp. 55–79.
5. Zhang, Z.; Duan, Z.; Xu, P.; Li, G. Food security of China: The past, present and future. *Plant Omics* **2010**, *3*, 183–189.
6. Liu, X.; Shi, L.; Qian, H.; Sun, S.; Wu, P.; Zhao, X.; Engel, B.A.; Wang, Y. New problems of food security in northwest china: A sustainability perspective. *Land Degrad. Dev.* **2020**, *31*, 975–989. [CrossRef]
7. Liu, X.; Shi, L.; Engel, B.A.; Sun, S.; Wang, Y. New challenges of food security in northwest china: Water footprint and virtual water perspective. *J. Clean. Prod.* **2020**, *245*, 118939. [CrossRef]
8. Conceição, P.; Levine, S.; Lipton, M.; Warren-Rodríguez, A. Toward a food secure future: Ensuring food security for sustainable human development in Sub-Saharan Africa. *Food Policy* **2016**, *60*, 1–9. [CrossRef]
9. Baig, M.B.; Shahid, S.A.; Straquadine, G.S. Making rainfed agriculture sustainable through environmental friendly technologies in Pakistan: A review. *Int. Soil Water Conserv. Res.* **2013**, *1*, 36–52. [CrossRef]
10. Dogliotti, S.; García, M.; Peluffo, S.; Dieste, J.; Pedemonte, A.; Bacigalupe, G.; Scarlato, M.; Alliaume, F.; Alvarez, J.; Chiappe, M. Co-innovation of family farm systems: A systems approach to sustainable agriculture. *Agric. Syst.* **2014**, *126*, 76–86. [CrossRef]
11. Gohar, A.A.; Cashman, A. A methodology to assess the impact of climate variability and change on water resources, food security and economic welfare. *Agric. Syst.* **2016**, *147*, 51–64. [CrossRef]
12. Nechifor, V.; Winning, M. Global economic and food security impacts of demand-driven water scarcity—Alternative water management options for a thirsty world. *Water* **2018**, *10*, 1442. [CrossRef]
13. Ringler, C.; Zhu, T. Water resources and food security. *Agron. J.* **2015**, *107*, 1533–1538. [CrossRef]
14. Umair, M.; Hussain, T.; Jiang, H.; Ahmad, A.; Yao, J.; Qi, Y.; Zhang, Y.; Min, L.; Shen, Y. Water-saving potential of subsurface drip irrigation for winter wheat. *Sustainability* **2019**, *11*, 2978. [CrossRef]

15. Dai, Z.; Fei, L.; Huang, D.; Zeng, J.; Chen, L.; Cai, Y. Coupling effects of irrigation and nitrogen levels on yield, water and nitrogen use efficiency of surge-root irrigated jujube in a semiarid region. *Agric. Water Manag.* **2019**, *213*, 146–154. [CrossRef]
16. Hao, K.; Fei, L.; Liu, L.; Jie, F. Improving Fruit Yield and Quality of Mountain Apple (Malus domestica Borkh. cv. Hanfu) by Light Deficit Surge-Root Irrigation in the Loess Plateau, China. *J. Soil Sci. Plant Nutr.* **2022**, *22*, 1506–1519. [CrossRef]
17. Abdalhi, M.A.; Jia, Z. Crop yield and water saving potential for AquaCrop model under full and deficit irrigation managements. *Ital. J. Agron.* **2018**, *13*, 267–278. [CrossRef]
18. Xu, Y.; Wang, Y.; Ma, X.; Liu, X.; Jia, Z. Ridge-furrow mulching system and supplementary irrigation can reduce the greenhouse gas emission intensity. *Sci. Total Environ.* **2020**, *717*, 137262. [CrossRef]
19. Hanson, E.D.; Cossette, M.K.; Roberts, D.C. The adoption and usage of precision agriculture technologies in North Dakota. *Technol. Soc.* **2022**, *71*, 102087. [CrossRef]
20. Gupta, R.; Tyagi, N.; Abrol, I. Rainwater management and Indian agriculture: A call for a shift in focus from blue to green water. *Agric. Res.* **2020**, *9*, 429–443. [CrossRef]
21. Chen, X.; Yang, S.; Ding, J.; Jiang, Z.; Sun, X. Effects of biochar addition on rice growth and yield under water-saving irrigation. *Water* **2021**, *13*, 209. [CrossRef]
22. Chen, X.; Yang, S.-H.; Jiang, Z.-W.; Ding, J.; Sun, X. Biochar as a tool to reduce environmental impacts of nitrogen loss in water-saving irrigation paddy field. *J. Clean. Prod.* **2021**, *290*, 125811. [CrossRef]
23. Ambika, A.K.; Mishra, V. Improved water savings and reduction in moist heat stress caused by efficient irrigation. *Earth's Future* **2022**, *10*, e2021EF002642. [CrossRef]
24. Washizu, A.; Nakano, S. Exploring the characteristics of smart agricultural development in Japan: Analysis using a smart agricultural kaizen level technology map. *Comput. Electron. Agric.* **2022**, *198*, 107001. [CrossRef]
25. Moysiadis, V.; Sarigiannidis, P.; Vitsas, V.; Khelifi, A. Smart farming in Europe. *Comput. Sci. Rev.* **2021**, *39*, 100345. [CrossRef]
26. Liu, X. Analysis of Crop Sustainability Production Potential in Northwest China: Water Resources Perspective. *Agriculture* **2022**, *12*, 1665. [CrossRef]
27. Lu, S.; Hu, Z.; Yu, H.; Fan, W.; Fu, C.; Wu, D. Changes of extreme precipitation and its associated mechanisms in Northwest China. *Adv. Atmos. Sci.* **2021**, *38*, 1665–1681. [CrossRef]
28. Xu, Z.; Zhang, W.; Li, M. China's grain production. *Mon. Rev.* **2014**, *66*, 25–37. [CrossRef]
29. Yang, M.; Pei, Y.; Li, X. Study on grain self-sufficiency rate in China: An analysis of grain, cereal grain and edible grain. *J. Nat. Resour.* **2019**, *34*, 881–889. [CrossRef]
30. Simon, G. Basic readings as an introduction to food security for students from the IPAD Master. In *SupAgro, Montpellier Attending a Joint Training Programme in Rome from 19th to 24th March 2012*; University of Roma Tre: Rome, Italy, 2012. Available online: https://www.fao.org/fileadmin/templates/ERP/uni/F4D.pdf (accessed on 6 June 2023).
31. Liu, X.; Xu, Y.; Engel, B.A.; Sun, S.; Zhao, X.; Wu, P.; Wang, Y. The impact of urbanization and aging on food security in developing countries: The view from Northwest China. *J. Clean. Prod.* **2021**, *292*, 126067. [CrossRef]
32. Chen, M.; Liu, W.; Lu, D. Challenges and the way forward in China's new-type urbanization. *Land Use Policy* **2016**, *55*, 334–339. [CrossRef]
33. Wang, Y.-S. The challenges and strategies of food security under rapid urbanization in China. *Sustainability* **2019**, *11*, 542. [CrossRef]
34. Dupla, X.; Lemaître, T.; Grand, S.; Gondret, K.; Charles, R.; Verrecchia, E.; Boivin, P. On-Farm Relationships Between Agricultural Practices and Annual Changes in Organic Carbon Content at a Regional Scale. *Front. Environ. Sci.* **2022**, *10*, 834055. [CrossRef]
35. Panettieri, M.; Moreno, B.; de Sosa, L.L.; Benítez, E.; Madejón, E. Soil management and compost amendment are the main drivers of carbon sequestration in rainfed olive trees agroecosystems: An evaluation of chemical and biological markers. *Catena* **2022**, *214*, 106258. [CrossRef]
36. Roy, P.; Pal, S.C.; Chakrabortty, R.; Saha, A.; Chowdhuri, I. A systematic review on climate change and geo-environmental factors induced land degradation: Processes, policy-practice gap and its management strategies. *Geol. J.* **2022**. [CrossRef]
37. Gleick, P.H. Transitions to freshwater sustainability. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 8863–8871. [CrossRef]
38. Abbou, M.; Chabbi, M.; Ayadi, M.; Zantar, S.; Benicha, M. Assessing environmental impacts of pesticide usage in oiled seed ecosystems using environmental pesticide pressure indicators: A case study of groundnut in Loukkos plain, north-west Morocco. *Environ. Dev. Sustain.* **2022**, 1–19. [CrossRef]
39. Li, F.; Shu-Yi, F.; Fu-Tian, Q. Fertilizer reduction policies in developed countries: Suitability and implications. *J. Agric. Resour. Environ.* **2017**, *34*, 15.
40. Pahalvi, H.N.; Rafiya, L.; Rashid, S.; Nisar, B.; Kamili, A.N. Chemical fertilizers and their impact on soil health. In *Microbiota and Biofertilizers, Vol 2: Ecofriendly Tools for Reclamation of Degraded Soil Environs*; Springer: Cham, Switzerland, 2021; pp. 1–20. [CrossRef]
41. Huang, D.; Wang, X. Research on Agricultural Production Efficiency of Guizhou Province Based on DEA-Malmquist Model. In *IOP Conference Series: Earth and Environmental Science*; IOP Publishing: Bristol, UK, 2019; Volume 310, p. 052068. [CrossRef]
42. Lobell, D.B.; Gourdji, S.M. The influence of climate change on global crop productivity. *Plant Physiol.* **2012**, *160*, 1686–1697. [CrossRef]

43. Kang, S.; Hao, X.; Du, T.; Tong, L.; Su, X.; Lu, H.; Li, X.; Huo, Z.; Li, S.; Ding, R. Improving agricultural water productivity to ensure food security in China under changing environment: From research to practice. *Agric. Water Manag.* **2017**, *179*, 5–17. [CrossRef]
44. Man, J.; Wang, D.; White, P.J. Photosynthesis and drymass production of winter wheat in response to micro-sprinkling irrigation. *Agron. J.* **2017**, *109*, 549–561. [CrossRef]
45. Rauf, S.; Al-Khayri, J.M.; Zaharieva, M.; Monneveux, P.; Khalil, F. Breeding strategies to enhance drought tolerance in crops. In *Advances in Plant Breeding Strategies: Agronomic, Abiotic and Biotic Stress Traits*; Springer: Berlin/Heidelberg, Germany, 2016; pp. 397–445.
46. Oguge, N.; Oremo, F. Fostering the use of rainwater for off-season small-scale irrigation in arid and semi-arid areas of Kenya. In *Rainwater-Smart Agriculture in Arid and Semi-Arid Areas*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 159–174.
47. Leal Filho, W.; de Trincheria Gomez, J. Preface: Rainwater-smart agriculture in arid and semi-arid areas. In *Rainwater-Smart Agriculture in Arid and Semi-Arid Areas*; Springer: Berlin/Heidelberg, Germany, 2018; pp. 1–5.
48. Liu, X.; Xu, Y.; Sun, S.; Zhao, X.; Wu, P.; Wang, Y. What is the potential to improve food security by restructuring crops in Northwest China? *J. Clean. Prod.* **2022**, *378*, 134620. [CrossRef]
49. Zhang, M.; Xiao, N.; Li, Y.; Li, Y.; Zhang, D.; Xu, Z.; Zhang, Z. Growth and Fruit Yields of Greenhouse Tomato under the Integrated Water and Fertilizer by Moistube Irrigation. *Agronomy* **2022**, *12*, 1630. [CrossRef]
50. Zhu, F.; Zhang, L.; Hu, X.; Zhao, J.; Meng, Z.; Zheng, Y. Research and Design of Hybrid Optimized Backpropagation (BP) Neural Network PID Algorithm for Integrated Water and Fertilizer Precision Fertilization Control System for Field Crops. *Agronomy* **2023**, *13*, 1423. [CrossRef]
51. Ren, B.; Guo, Y.; Liu, P.; Zhao, B.; Zhang, J. Effects of urea-ammonium nitrate solution on yield, N2O emission, and nitrogen efficiency of summer maize under integration of water and fertilizer. *Front. Plant Sci.* **2021**, *12*, 700331. [CrossRef]
52. Tofa, A.I.; Kamara, A.Y.; Babaji, B.A.; Akinseye, F.M.; Bebeley, J.F. Assessing the use of a drought-tolerant variety as adaptation strategy for maize production under climate change in the savannas of Nigeria. *Sci. Rep.* **2021**, *11*, 8983. [CrossRef]
53. Zhou, B. *Research on Influencing Factors of Food Security Based on Agriculture Sustainable Development*; Shenyang Agricultural University: Shenyang, China, 2015.
54. PRC. *Central People's Government of the People's Republic of China, the CPC Central Committee and The State Council "Opinions on Several Policies to Promote the Increase of Farmers' Income"*; PRC: Beijing, China, 2003.
55. Shiferaw, B.; Prasanna, B.M.; Hellin, J.; Bänziger, M. Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Secur.* **2011**, *3*, 307–327. [CrossRef]
56. PRC. *Notice of The General Office of the State Council on the Implementation of the CPC Central Committee and The State Council "Policy and Measures Concerning Several Policy Opinions on Further Strengthening Rural Work and Improving the Overall Agricultural Production Capacity"*; PRC: Beijing, China, 2005.
57. Xu, Y.; Geng, Y.; Gao, Z.; Xiao, S.; Zhang, C.; Zhuang, M. Accounting greenhouse gas emissions of food consumption between urban and rural residents in China: A whole production perspective. *Front. Energy* **2022**, *16*, 357–374. [CrossRef]
58. Lian, Y.; Gu, L.; Yang, L.; Wang, L.; Li, H. The Reasonableness and Spatial Differences of the Food Consumption Structure of Urban and Rural Residents in China, 2015–2021. *Foods* **2023**, *12*, 1997. [CrossRef]
59. Karthika, D.P.; Karthikeyan, P. Urbanization, Food Insecurity and Agriculture-Challenges for Social Sustainable Development. *Probl. Ekorozw.–Probl. Sustain. Dev.* **2016**, *12*, 157–162.
60. Seto, K.C.; Ramankutty, N. Hidden linkages between urbanization and food systems. *Science* **2016**, *352*, 943–945. [CrossRef]
61. Popkin, B.M. Rural Areas Drive Increases in Global Obesity. *Nature* **2019**, *569*, 200–201. [CrossRef] [PubMed]

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