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Research on the Factors Influencing the Security of Grain Supply Capacity in Sichuan Province Based on PLS Structural Equation Modelling

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Abstract

Sichuan Province, distinguished as one of the top performers among China's 13 main grain-producing provinces, holds unique advantages in the western region. The continuous increase in grain production lays a solid groundwork for upholding the country's food security. Grounded in five dimensions—social, economic, technological, resource, and environmental—this article establishes a security evaluation system for the grain supply capacity of Sichuan Province, incorporating 14 specific indicators, and utilizes a PLS structural equation model to investigate the diverse factors influencing the security of Sichuan Province's grain supply capacity. Findings reveal that social and technological advancements directly negatively affect the security of the grain supply capacity, while economic growth, environmental progress, and resource enhancement directly positively influence grain supply capacity security. It also corroborates that a sustainable grain supply capacity necessitates the harmonious development of these five facets, each being essential. As a result, strategies to safeguard the security of Sichuan Province's grain supply capacity are put forward, aiming to offer decision-making references for strengthening and elevating Sichuan's grain supply capability and constructing an advanced "Heavenly Granary".

Keywords: food supply capacity security, Sichuan Province, food supply capacity security evaluation system, PLS structural equation modelling

1. Introduction

Sichuan Province is renowned for its abundant agricultural resources and high-quality crops, establishing itself as not only an important agricultural base in China but also as the most crucial agricultural province in Western China. It plays a vital role in ensuring national food security. On May 1, 2021, the province issued the "Sichuan Province Food Security Protection Regulations," proposing new legislative initiatives to firmly establish the "Tianfu food bowl" concept and ensure food security. In 2022, the Sichuan Provincial Party Committee's No. 1 document emphasized that the work on "agriculture, rural areas, and farmers" should be given top priority in food security and called for strengthened supervision and management of food security. In June 2022, during an inspection and research visit to Meishan City, General Secretary Xi Jinping proposed the construction of a more comprehensive "Tianfu Granary" system providing strong support and solid guiding principles for Sichuan's food security endeavors in the new era. The focal point of ensuring food security lies in increasing the yield of crops so as to meet people's needs in necessary situations (Pan et al., 2022). The condition of food production and supply in Sichuan Province is key to national food security (Huang & Zhang, 2023). Conducting in-depth research into the factors affecting food supply in Sichuan Province can provide a scientific basis for food security in Sichuan Province and even the entire country.

Huang and Zhang (2023) believe that Sichuan Province has a variety of climate types with significant vertical changes, and it often suffers from severe and widespread droughts and floods. Compared to other provinces, the grain supply in Sichuan Province is more significantly affected by the climatic environment. Liu et al. (2022), and Lu and Liu (2017) point out in their respective studies that the overuse of chemical fertilizers has seriously damaged the agricultural ecosystem, creating an "environmental penalty" effect that severely hinders the sustainable development of grain production. Hu and Chen (2021) utilized the GM model to analyze the factors influencing grain yield in Sichuan and found that the construction level of some grain and oil bases, due to misallocated financial support, is far inferior to that of cash crop bases, making it difficult to effectively ensure the efficiency and benefits of grain output. Xiong et al. (2022), Zhao and Li (2019), Liu and Yang (2022), and Lv et al. (2023) have discovered that Sichuan's topography is predominantly hilly and mountainous, with a large area of sloping farmland, characterized by irregular terraces and ridges. The use of agricultural machinery faces serious challenges due to "difficulty in accessing fields and operating machinery," which impedes the level of mechanization in grain production and the modernization of the grain industry in Sichuan Province, thus affecting the supply of grain. Wei (2021), Xu and Zhao (2021), and Xu (2020) propose in their studies that the continuous rise in agricultural production costs has severely impacted the per-unit yield of grain crops, leading to a sharp decline in farmers' enthusiasm for planting. Currently, grain production in Sichuan Province relies heavily on vulnerable groups such as the elderly, women, and children, and the agricultural workforce is facing a dual pressure of declining numbers and quality, posing a significant challenge to grain production. All the above studies analyze from the perspective of single influencing factors, but the interconnections and interactions between individual factors cannot be ruled out, and it would be more appropriate to consider all factors within the same measurement scope comprehensively.

Compared to studies focusing on individual factors, Zhang and Yang (2010) approached from perspective of sustainable development, and constructed an evaluation system for food security, which encompasses five dimensions: production, economy, society, resource environment, and agricultural technology, with each dimension containing individual influencing factors, thereby providing a more comprehensive consideration of the influencing conditions. However, they only proposed a theoretical framework without empirically testing its validity and correctness with a model. Whereas Zhou et al. (2015), building upon this foundation, introduced specific indicators such as the grain production fluctuation index, grain self-sufficiency rate, grain reserve rate, per capita grain possession, poverty incidence rate, and grain trade dependency as dependent variables for food security, and employed a PLS structural equation model to conduct an empirical analysis of the various dimensions, which to some extent verified the correctness of the food security framework and led to conclusions: that apart from social development having a direct negative impact on food security, technological support, resource factors, environmental conditions, and the agricultural economy all have direct positive impacts on food security, and it was also concluded that resource factors, technological support, and environmental conditions have a positive impact on the agricultural economy. Furthermore, Zhang et al. (2023) also built upon this to construct a new food security evaluation system (Zhang, & Yang, 2010). Such as the dimensions of supply capacity composed of specific indicators including the food production volatility rate, sown area of grain, grain yield per unit, per capita water resources, per capita arable land area, and per capita grain possession and applied the entropy-weighted TOPSIS model to analyze factors affecting food security finding that in some cases, due to shortcomings in technological development, the dimension of technological development had a negative effect on the increase in food supply during that period. The above studies to some extent avoid biases in results or recommendations that arise from considering only single factors but they are all geared towards national food security and do not delve into the characteristics influencing grain supply in Sichuan Province. This also indirectly reflects the urgency and necessity of comprehensively assessing the factors affecting food supply in Sichuan Province.

In summary, existing research provides a foundational basis for this study, yet there is a deficiency in systematic studies on the determinants impacting the security of grain supply capabilities. Systematic investigations specifically centered on Sichuan Province to examine the factors affecting grain supply security are even rarer. Owing to Sichuan Province's distinctiveness in aspects such as resources, technology, economic conditions, environment, and societal structure, it is more pertinent to delve into the factors influencing the security of the grain supply capacity by establishing a specialized assessment framework as a foundational step. Furthermore, the selection of an empirical model that is suitable for holistic and integrative analysis is recommended.

Based on existing research findings and the actual situation in Sichuan Province, this paper develops a new evaluation system specifically for assessing the security of grain supply capacity in Sichuan Province, comprising five dimensions: social, economic, technological, resource, and environmental, each encompassing factor indicators affecting grain production in Sichuan Province as proposed by existing research. Relevant indicator data from 1931 to 2022 are selected, and appropriate data processing is performed for missing data. The PLS structural equation model is employed to conduct an empirical study on the factors influencing the security of grain supply capacity in Sichuan Province. The results indicate that social and technological developments have a direct negative impact on the security of grain supply capacity, whereas economic, environmental, and resource developments have a direct positive impact on the same. Consequently, this paper proposes comprehensive, systematic strategies to enhance the grain supply capacity in Sichuan Province, aiming to promote the stable development of grain production in the province and to create a higher-level "Tianfu Granary".

2 Evaluation System Construction

2.1 Principles of Evaluation System Design

Food supply security is contingent upon a variety of factors, including resources, environment, technology, and human capital. These elements constitute an integrated system that is systematic, complex, and scientific. The establishment of a food supply security assessment system should adhere to several principles: (a) The principle of systematicity, which views the assessment system as a unit where components and levels are independently yet intimately interconnected. The overall structure must encapsulate the totality of food supply security while the subsystems should reflect individual aspectual characteristics. (b) The principle of scientific nature, emphasizing the need for a scientific and substantiated selection of evaluation indicators. (c) The principle of guidance, with chosen indicators providing direction and instruction, capable of highlighting the critical points for future development in food supply security and offering strategic direction. (d) The principle of operability, where indicators should be quantifiable and the data should be easily accessible. (e) The principle of coordination, which involves designing an indicator system that balances the comprehensiveness and representativeness of the indicators and manages the relationship between past, present, and future indicators effectively (Cao, & Li, 2020; Zhou, 2010; Zhang et al., 2015; Qi & Zhang, 2020; Li & Fu, 2000; Ye et al., 2021).

Drawing from an in-depth understanding of the concept of food supply capacity in Sichuan Province, and consulting pertinent research outcomes (Zhang et al., 2023; Zhou et al., 2015; Zhang & Yang, 2010), an assessment system for food supply capacity security in Sichuan Province was crafted, emanating from five developmental facets: societal, economic, technological, resource-based, and environmental. This system includes 14 distinct indicators, among which are the Engel coefficient for rural households, agricultural labor productivity, the usage volume of agricultural fertilizers, and the total power output of agricultural machinery, providing a comprehensive framework for evaluating the region's food supply security (Table 1).

Table 1. Evaluation system for food supply capacity security

Level 1 indicators	Secondary indicators	unit (of measure)	Calculation of indicators
Social development	Engel's coefficient for rural households	%	-
	Consumer price index for food for rural inhabitants	Previous year's price = 100	-
	Consumption level index for rural residents	Previous year = 100	-
Economic development	Agricultural labour productivity	Million yuan/person	Ratio of gross agricultural output to the number of persons employed in the primary sector
	Agricultural land productivity	million/hm^2	Ratio of gross agricultural output to total sown area under crops
	Share of agricultural expenditure in fiscal expenditure	%	-
Technological development	Gross power of agricultural machinery	kilowatt (unit of electric power)	-
	Agricultural professionals	man	-
Resource development	Total sown area of crops	hectares	-
	Effective irrigated area	thousand hectares	-
	Land replanting index	%	Total sown area of crops/area of arable land
Environmental development	Soil erosion control area	thousand hectares	-
	Agricultural fertiliser application rates	tonnes	-
	Crops affected	hectares	-

3 Data Sources and Research Methodology

3.1 Data Sources and Processing

This paper selects a panel data set consisting of 92 groups of relevant indicators for Sichuan Province from 1931 to 2022. The data involved in the research mainly comes from sources such as the "Sichuan Statistical Yearbook," "China Agricultural Statistics," "China Rural Statistical Yearbook," "Statistical Communique on the National Economic and Social Development of Sichuan Province," "China Statistical Yearbook," "China Water Resources Yearbook," and others. Data on per capita grain possession is mainly derived from the "Sichuan Statistical Yearbook," "China Rural Statistical Yearbook," "Statistical Data on Rural China in the Western Regions," and "China Development Report." Information on agricultural professionals is primarily sourced from the "China Science and Technology Statistical Yearbook." Data on the Engel coefficient for rural households is mainly derived from sources including the "Statistical Communique on the National Economic and Social Development of Sichuan Province," "China Statistical Summary," "Compilation of Sixty Years of Statistical Data of New China," and "China Regional Economic Monitoring Report." The proportion of agricultural expenditure in fiscal spending is primarily sourced from "The Leap of History—30 Years of Rural Reform and Opening Up," and data on grain yield per unit area mainly comes from the "China Grain Yearbook" and "Sixty Years of New China Agriculture Statistical Data." Appropriate data processing is applied to missing data for certain years to maintain data integrity (Table 2).

Table 2. Descriptive statistics

Level 1 indicators	Secondary indicators	N	Average value	Standard Deviation
social development	Engel's coefficient for rural households	92	51.53297	10.51259
	Consumer price index for food for rural inhabitants	92	104.6811	9.745507
	Consumption level index for rural residents	92	106.548	7.025883
economic development	Agricultural labour productivity	92	0.975468	1.089739
	Agricultural land productivity	92	1.868087	1.65326
	Share of agricultural expenditure in fiscal expenditure	92	9.399413	3.323092
technological development	Gross power of agricultural machinery	92	2503.071	1435.215
	Agricultural professionals	92	47948.19	3731.159
Resource development	Total sown area of crops	92	933.9897	29.65847
	Effective irrigated area	92	2691.965	191.2644
	Land replanting index	92	20.38954	3.061662
Environmental development	Soil erosion control area	92	9254.462	2994.137
	Agricultural fertiliser application rates	92	209.1208	35.59348
	Crops affected	92	205.6108	123.7464

3.2 Interpretation of Indicators and Explanation (Zhang et al., 2023; Zhou et al., 2015; Zhang & Yang, 2010)

(1) Social development: This index system focuses on assessing the grain consumption capacity and its level among rural residents, comprehensively reflecting the living conditions and income levels of rural residents. The living and income levels of rural residents not only determine whether grain producers choose to remain in the countryside for farming or move to cities for non-agricultural jobs but also have a significant impact on the security of grain supply capacity. The evaluation indicators specifically include the Engel coefficient for rural households—the ratio of total food expenditure to total consumption expenditure, which indirectly shows the proportion of grain consumption in total household expenditure—the grain consumption price index for rural residents, revealing the trend of changes in grain market prices, and affecting the living expenses of rural residents. Additionally, the consumer level index for rural residents measures the degree of consumption of material goods and services by rural residents, that is, the quality of their living standards.

(2) Economic development: The index system primarily evaluates the efficiency and effectiveness of grain production and assesses the economic sustainability of food supply security based on this. This economic sustainability refers to ensuring the continuous growth of land productivity while alleviating the pressure on land resources, maintaining the profit margin of capital in food production and management, ensuring the availability of production resources, and enhancing the self-sustaining and development capabilities of the food production system to achieve long-term stable growth of food supply. The system evaluates through three key indicators:

agricultural labor productivity, which is quantified by the ratio of total agricultural output value to the number of primary industry workers; agricultural land productivity, which measures the production efficiency of crops per unit sown area using the ratio of total agricultural output value to the crop sown area; and the proportion of agricultural expenditure in fiscal spending, which reflects the stability and guarantee level of financial support for grain production development.

(3) Scientific and technological development: The index system assesses modern agricultural science and technology, advanced material equipment, and the quality of agricultural workers, guiding the selection of appropriate grain production and management models and resource utilization methods under regional actual conditions. It addresses the effectiveness of enhancing or improving the efficiency of grain supply and production capacity. The system mainly covers two evaluation indicators: total agricultural machinery power, which represents the level of mechanization in grain production and the contribution of modern agricultural science and technology to ensuring the capacity of grain supply, quantified by the ratio of total agricultural machinery power to the crop sown area; and the agricultural professional personnel indicator, which reflects the quality of the labor force engaged in agricultural production. This quality directly affects the level of grain production, thereby determining the security of grain supply capacity.

(4) Resource development: This index system focuses on assessing the degree of sustainable utilization of natural resources and their impact on the security of food supply capacity. It also reflects the carrying capacity of agricultural resources and the buffering capacity of the environment. The evaluation system includes three core indicators: total crop sown area, effective irrigation area, and land multiple cropping index. The total crop sown area reflects the land resources invested to ensure food supply security. The effective irrigation area reveals the efficiency of water resource utilization in food cultivation. The land multiple cropping index evaluates the utilization status of arable land and reveals whether the cultivation system effectively combines planting with land conservation to regulate and enhance the quality of cultivated land, preventing the overexploitation of resources. This index is quantified by the ratio of the crop sown area to the arable land area.

(5) Environmental development: This index system aims to evaluate the extent of ecological environment support for food supply security and to highlight the green sustainability characteristics of food supply security. The system includes three core evaluation indicators: the area of soil and water conservation, the amount of agricultural fertilizer applied, and the area of crops affected by disasters. The area of soil and water conservation reflects the number, reserves, and potential for sustainable development of arable land, which is a key indicator of the green development of productive farmland. The amount of agricultural fertilizer applied indicates the level of pollution to soil and water resources caused by fertilizers, which could threaten the growth of food crops and their ecological environment, thereby affecting food supply. The area of crops affected by disasters shows the extent of damage to the ecological environment of food crops by natural disasters and pests.

3.2 PLS Structural Equation Modelling

3.2.1 Introduction to the Model

Structural Equation Modeling (SEM) is a methodology that traces its roots back to the early 20th century, introduced by Wright, and has been extensively applied across various fields today such as sociology, psychology, educational sciences, and econometrics. In SEM, variables are categorized into two types: one being latent variables, which are intangible and cannot be directly observed or measured, serving to explore unknown issues; and the other being manifest variables, which are tangible and can be observed and measured, utilized for describing and predicting future developmental trends. SEM serves as a powerful tool for articulating the relationships between latent variables, comprising structural and measurement models (Zhou et al., 2015; Yi, 2008), where the structural model is employed to depict the interrelations among latent variables, while the equations are used to represent these relationships.

$$\eta = B\eta + \Gamma\xi + \xi \tag{1}$$

In this context, η represents the endogenous variables, ξ denotes the exogenous variables, and ξ is indicative of the random error terms, which account for the variance in η that cannot be explained. B is the matrix of coefficients for the endogenous variables, serving to describe the relationships among the endogenous variables η. Γ is the matrix of coefficients for the exogenous variables, used to describe the relationships between the exogenous variables ξ and the endogenous variables η.

The measurement model is used to describe the relationship between latent and manifest variables, and the equation is:

$$X = \Lambda x\xi + \delta y = \Lambda x\eta + \varepsilon \tag{2}$$

In this model, "x" stands for an exogenous latent variable, the value of which can be ascertained via empirical measurements. "y" symbolizes the endogenous latent variable η, whose value is likewise obtainable through experimental measurement. The matrix Λx is the matrix of factor loadings for "x" on ξ, whereas Λy indicates the matrix of factor loadings for "y" on η. The symbol δ corresponds to the measurement bias associated with "x", and ε refers to the measurement deviation of "y".

Experience has shown that structural equations can be formulated using path diagrams, offering a notable benefit: it presumes no multicollinearity among variables, thereby ensuring that, even in the presence of multicollinearity, it does not impede the algebraic calculations of certain matrices, thus preventing scenarios of perfect collinearity or singular matrices, which simplifies the resolution of structural equations (Si et al., 2014; Wang et al., 2022). Among these, Partial Least Squares and the Covariance Matrix Method (PLS) are the most prevalent techniques, which can deliver precise solutions tailored to the sample's attributes and the research objectives, fulfilling particular research requisites.

Using Sichuan Province as a reference point, a food supply capability security assessment framework is to be established, addressing a gap where articles systematically investigating the determinants of food supply capacity security in Sichuan Province are scarce. The theoretical underpinnings are relatively weak, with the validation of influential factors remaining in an exploratory phase. Moreover, one of the strengths of PLS-SEM is its focus on extracting information from the sample data, and its sample size requirement is not as high as that of CB-SEM, with a minimum threshold ranging from 30 to 100 samples (Meng, 1994; Yao et al., 2005). This aligns with the necessity of this article to perform research analysis under the condition of having a limited number of case study subjects.

3.2.2 Selection of Variables

Based on Equations (1) and (2), this paper identifies social development, economic development, technological development, resource development, and environmental development as latent variables in the structural equation. Each primary indicator's corresponding secondary indicators are treated as manifest variables in the structural equation. Furthermore, drawing on related research findings (Zhang et al., 2023; Zhou et al., 2015; Zhang & Yang, 2010) and conducting a scientifically sound analysis, the security of food supply capacity is measured using the following indicators: the coefficient of variation in food production, food yield per unit area, and per capita food possession (Table 3).

Table 3. Selection of variables

Latent variable	Notation	Phanero-variable (math.)	Notation
Food supply capacity security	η	the coefficient of variation in food production	y1
		food yield per unit area	y2
		per capita food possession	y3
Social development	ξ1	Engel's coefficient for rural households	x1
		Consumer price index for food for rural inhabitants	x2
		Consumption level index for rural residents	x3
Economic development	ξ2	Agricultural labour productivity	x4
		Agricultural land productivity	x5
		Share of agricultural expenditure in fiscal expenditure	X6
Technological development	ξ3	Total power of agricultural machinery	X7
		Agricultural professionals	X8
Resource development	ξ4	Total sown area of crops	X9
		Effective irrigated area	X10
		Land replanting index	x11
Environmental development	ξ5	Soil erosion control area	x12
		Agricultural fertiliser application rates	x13
		Crops affected	x14

3.2.3 Modelling Assumptions

The structural model outlines the interrelations between latent variables, employing path diagrams or equations to depict the relationships among these variables, thus facilitating a deeper comprehension of their interactive dynamics. Therefore, drawing upon the research results of prior academics on the determinants of food supply capacity security (Zhang et al., 2023; Zhou et al., 2015), the subsequent hypotheses are put forward, accompanied by the construction of a conceptual framework. As depicted in Figure 1:

H1: Economic development has a positive impact on food supply capacity security;

H2: Environmental development has a positive impact on food supply capacity security;

H3: Resource development has a positive impact on food supply capacity security;

H4: Social development has a negative impact on food supply capacity security;

H5: S&T development has a negative impact on food supply capacity security

H6: Scientific and technological development has a positive impact on economic development;

H7: Resource development has a positive impact on economic development.

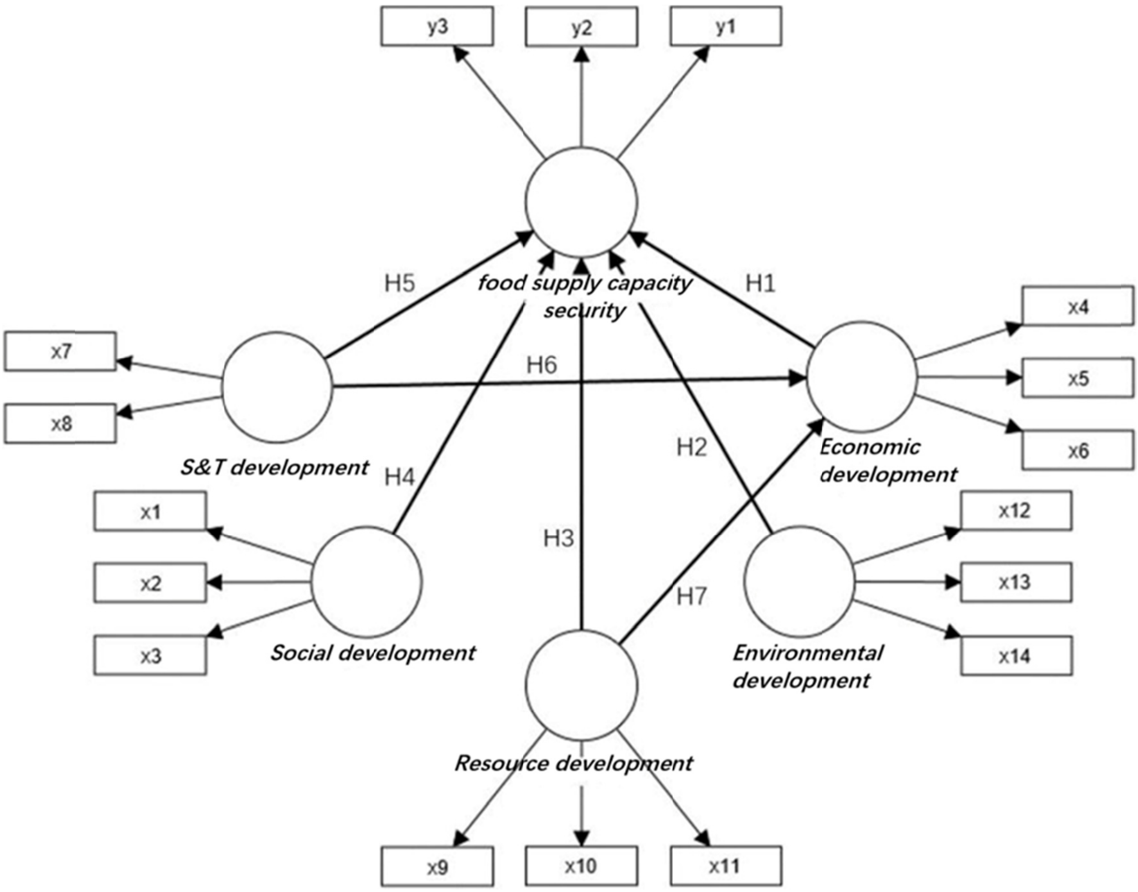

Figure 1. Framework diagram of research hypotheses on factors affecting food supply capacity security

4. Empirical Analysis

Evaluating structural equation models is characterized by significant complexity (Yi, 2008). Hence, throughout the assessment procedure, one must not only scrutinize the overall fit of the model, but also to holistically assess elements including the parameters, structural equations, and the adequacy of fit for the measurement equations.

4.1 Reliability Test

Reliability testing refers to the consistency, stability, and dependability of test results, which is commonly expressed in terms of internal consistency to indicate the level of test reliability. The higher the reliability coefficient, the more consistent, stable, and reliable the test results are. Generally, a Cronbach's alpha value greater than 0.7 in the final test results is considered as passing the reliability test (Zhou et al., 2015; Zhang & Wang, 2016). The PLS structural equation model also provides another reliability indicator, the CR value, which, similar to the Cronbach's alpha, indicates good reliability of the model if the final CR value exceeds 0.7. Based on the reliability testing results of the latent variables (Table 4), it can be observed that both the internal consistency reliability values (Cronbach's alpha) and composite reliability values (CR) exceed 0.7, indicating that each latent variable has good reliability and has passed the reliability test.

Table 4. Results of confidence test

	Cronbach's alpha	CR
Food supply capacity security	0.894436	0.857398
social development	0.825624	0.841167
economic development	0.796481	0.776510
technological development	0.809613	0.843879
Resource development	0.788552	0.761635
Environmental development	0.839375	0.861504

4.2 Validity Tests

Validity comprises discriminant validity and convergent validity. Discriminant validity measures the degree of difference between two latent variables and is confirmed if the square root of the AVE value exceeds the absolute values of its correlations with other latent variables. When the AVE value exceeds 0.5 (Zhou et al., 2015; Zhang & Wang, 2016), it is an indication of high convergent validity, which evaluates whether multiple manifest variables related to the same latent construct demonstrate high internal consistency. The data from Table 5 reveals that the square roots of the latent variables' AVEs all exceed the absolute values of their correlation coefficients with other latent variables, indicating strong discriminant validity and differentiation among them. Furthermore, data from Table 6 shows that all AVE values exceed 0.5, signifying that the model possesses good convergent validity, or in other words, strong internal consistency.

Table 5. Results of the discriminant validity test

	Environmental development	Social development	Technological development	Food supply capacity security	Economic development	Resource development
Environmental development	0.935761					
Social development	0.902442	0.867294				
technological development	0.618753	0.724087	0.975811			
Food supply capacity security	0.871245	0.760832	0.688002	0.881093		
economic development	0.766489	0.796248	0.922954	0.756424	0.863439	
Resource development	0.528732	0.523174	0.631682	0.705128	0.776202	0.648020

Table 6. Results of convergent validity test

	AVE
Food supply capacity security	0.876359
social development	0.824044
economic development	0.745831
technological development	0.951038
Resource development	0.639267
Environmental development	0.843356

4.3 Path Validity Tests and Model Validity

The Bootstrapping algorithm was employed to test the path validity, and Figure 2 clearly shows that all hypotheses have passed the test, with detailed results presented in Table 7. Additionally, R2 indicates the extent to which one latent variable is explained by other latent variables, with an R2 greater than 0.67 suggesting a strong explanatory power (Zhang & Wang, 2016). It is evident from the values within the ellipses in Figure 2 that the R2 values for the latent variables of food supply security and economic development, which are explained by other latent variables, are very high, demonstrating the model's strong explanatory power.

Table 7. Structural model path validity test

Pathways to structural modelling	T-value	P-value	Path factor	Results of hypothesis testing
H1: Economic development→food supply capacity security	2.218	0.022	0.308**	Support
H2: Environmental development→food supply capacity security	2.183	0.029	0.570**	Support
H3: Resource development→food supply capacity security	2.564	0.010	0.376**	Support
H4: Social development→food supply capacity security	2.881	0.004	-0.490***	Support
H5: Scientific and technological development→food supply capacity security	2.742	0.006	-0.790***	Support
H6: Scientific and technological development→economic development	11.737	0.000	0.718***	Support
H7: Resource development→economic development	3.940	0.000	0.322***	Support

Note. ** indicates significant at the 5 per cent confidence level; *** indicates significant at the 1 per cent confidence level.

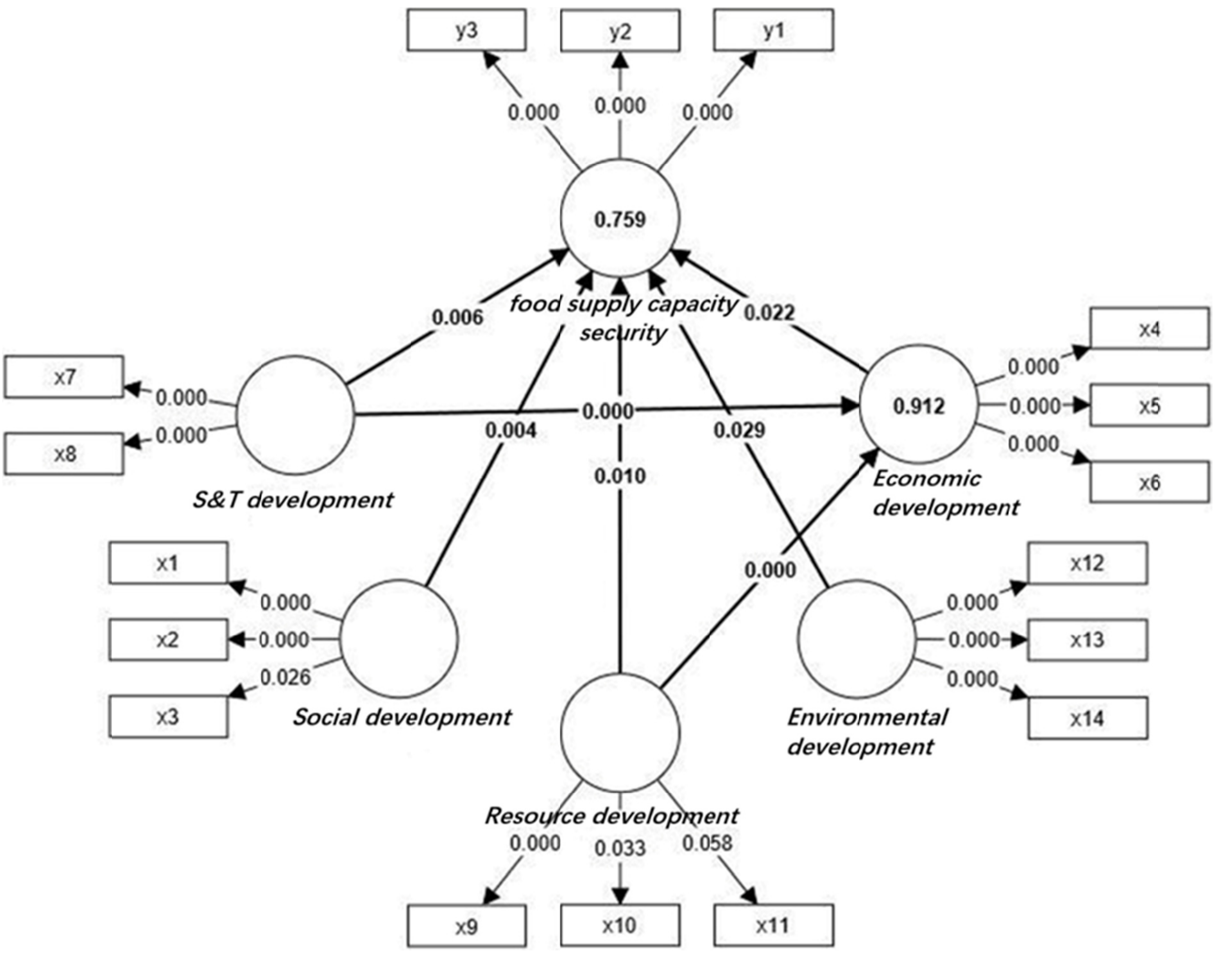

Figure 2. PLS structural equation model path validity test results

4.4 Empirical Results and Impact Effects

(1) The results of the Partial Least Squares (PLS) analysis indicate that social development (-0.490) and technological development (-0.790) have a direct negative impact on food supply security. Conversely, economic

development (0.308), environmental development (0.570), and resource development (0.376) are shown to have a direct positive influence on food supply security.

Technological and resource development indirectly affect food supply security through economic development. On the hand, these two factor variables have a direct positive impact on economic development, which is specifically demonstrated by the figures for technological development (0.718) and resource development (0.322). On the other hand, the effect of economic development on the security of food supply capacity is measured at (0.308). Through calculation, it is concluded that technological development (0.718 × 0.308 = 0.221) and resource development (0.322 × 0.308 = 0.099) have an indirect impact on the security of the food supply capacity.

Compiling the direct and indirect of each factor variable on the security of food supply allows for the calculation of the cumulative impact effect. Social progress (-0.490) and technological advancement (-0.569) exert a generally adverse effect on the security of food supply capacity. On the other hand, the aggregate impact of environmental development (0.570), resource development (0.475), and economic development (0.308) is positive, with a successive reduction in their effectiveness. Detailed insights into the impact effects related to each variable's pathway can be found in Table 8.

Table 8. Structural modelling path impact effects

Pathways to structural modelling	Direct impact	Indirect impact	Total impact
H1: Economic development→food supply Capacity security	0.308		0.308
H2: Environmental development→food supply capacity security	0.570		0.570
H3: Resource development→food supply capacity security	0.376	0.322 × 0.308 = 0.099	0.475
H4: Social development→food supply capacity security	-0.490		-0.490
H5: Scientific and technological development→food supply capacity security	-0.790	0.718 × 0.308 = 0.221	-0.569
H6: Scientific and technological development→economic development	0.718		0.718
H7: Resource development→economic development	0.322		0.322

(2) The path coefficient of social development on food supply security is -0.490 (with a p-value < 0.01, indicating significance at the 1% confidence level), suggesting that for every unit of progress in social development, food supply security decreases by 0.490 units. This may be attributed to the continuous rise in costs associated with agricultural infrastructure construction and operation, land rent, labor, and the leasing of agricultural machinery. However, despite stable food prices, the net income from cereal crops remains low, leading to reduced planting enthusiasm among farmers and a significant decrease in the cultivated area in certain regions (Wei, 2021). Farmers' planting activities appear unplanned and unprofessional, with some even opting to abandon farming or transfer their land to neighbors at no cost (Wei, 2021). Economic, environmental, resource, and technological developments may also have an influence on this situation. For instance, in economic development, a decrease in the proportion of agricultural expenditure to fiscal spending leads to increased costs for agricultural infrastructure construction and operation, land rent, and labor, which are difficult for farmers to bear. In the environmental domain, an increase in the area of crops affected by disasters may directly lead to reduced food production or quality, failing to meet farmers' expected returns and potentially adversely affecting their consumption levels. For example, in the resource sector, an excessive increase in the multiple cropping index may lead to reduced soil fertility, thereby affecting food production. Moreover, in the sphere of technological development, the total power of agricultural machinery has a significant effect on per capita food production, which may lower the consumption levels of rural residents and have a negative impact on social development.

The impact path coefficient of technological development on food supply security is -0.569 (p-value < 0.01, significant at the 1% confidence level), indicating that for every unit increase in technological advancement, food supply security decreases by 0.569 units. This may be due to the diversity of planting systems in Sichuan Province, which poses challenges to the development of suitable machinery; the low rate of return on agricultural investment and the weakness at both the supply and demand sides of the agricultural machinery market contribute to this issue; inadequate policy support and an underdeveloped technical service system are also factors; small farming machinery is widely used, whereas large-scale machinery is scarce (Liu & Yang, 2022). Furthermore, influenced by urbanization and industrialization, the earnings from non-agricultural industries significantly exceed those from agriculture, leading to an increased opportunity cost for farmers in agricultural production, which in turn causes a large number of agricultural professionals to shift to non-agricultural industries. This leads to a shortage of grassroots agricultural technical personnel (Zhao & Li, 2019). Economic, environmental, resource, and social development factors may also influence this situation, with insufficient funding potentially hindering the development of agricultural science and technology, challenges to agricultural innovation due to natural environmental constraints and the demand for efficient resource utilization, dampening the enthusiasm for innovation. As society develops, an increasing number of agricultural professionals are migrating to the non-agricultural sector, resulting in a lack of human resources for agricultural science and technology R&D, which could lead to a lack of technological impetus in agricultural development, consequently affecting the security of food supply capacity (Liu & Yang, 2022).

The impact path coefficients of economic, environmental, and resource development on the security of food supply capacity are 0.308, 0.570, and 0.475, respectively (all p-values < 0.05, significant at the 5% confidence level), indicating that these variables have a relatively large contribution. The primary reason is that fiscal agricultural investments can improve basic agricultural conditions, enhance disaster resilience, and increase the sustained output rate of arable land; Additionally, agricultural subsidy policies also contribute to directly increasing farmers' incomes. Both measures can maintain and enhance farmers' enthusiasm for grain production, ensure the stability of the agricultural labor force, and further secure the safety of food supply capacity (Peng & Lu, 2010). Food security issues are closely related to climate change, natural disasters, and pest infestations, and a well-developed natural disaster prevention and control system is crucial for ensuring food security (Su et al., 2022). Food production is subject to resource constraints, with arable land being the core resource, and the effective utilization of arable land is key to ensuring the security of food production (Nie, 2015).

5. Recommendations

This study indicates that societal and technological advancements have had a negative impact on the security of food supply capacity in Sichuan Province. However, economic growth and sustainable development of resources and the environment have a positive effect on the food supply capacity security in the province. Coordination across five dimensions is essential, with each being indispensable to the others. Concrete recommendations for various dimensions should be proposed based on the results of empirical research, aimed at comprehensively and systematically ensuring the security of food supply capacity in Sichuan Province.

(1) The development of the economy, environment, and resources has a significant positive impact on the security of food supply capacity, with its contribution being particularly notable.

Firstly, environmental development is crucial for the security of food supply capacity, underscoring the importance of ecological conservation in ensuring food security, reflecting the concept that "lucid waters and lush mountains are invaluable assets." This study defines the latent variables of environmental development as the area of soil and water loss control, the amount of fertilizer applied, and the area affected by crop disasters, which are three manifest variables. Therefore, to enhance environmental development, we can start with the following aspects: Enhance soil and water conservation measures, as well as water source maintenance, to mitigate soil erosion. Improve the efficiency of fertilizer and water resource usage to prevent adverse effects on food production caused by pesticide residues and heavy metal contamination. Intensify training in agricultural technology knowledge, such as corn air-permeable dense planting techniques, high-quality rice integrated cultivation technology, and high-yield soybean cultivation techniques. Simultaneously apply soil testing and formulated fertilization techniques and improved pesticide application methods, use aqueous emulsions instead of oil emulsions and pesticide additives, master modern plant protection machinery, and implement specialized pest and disease control. Consequently, reduce farmers' over-reliance on agricultural inputs such as pesticides, chemical fertilizers, and agricultural films, and instead rely more on technology-driven cultivation methods. Additionally, efforts should be intensified in the innovation of disaster prevention and mitigation technologies to alleviate the impact of natural disasters on food supply.

The impact of resource development on the security of food supply capacity is second only to environmental development, fully validating that food production is a resource-constrained activity (Nie, 2015). Resource elements are critical material carriers for engaging in agricultural production and ensuring food security (Zhou et al., 2015). In this paper, the latent variable of resource development is composed of three manifest variables: the total sown area of crops, the effective irrigation area, and the multiple cropping index. Therefore, to enhance resource development, one should start with the following aspects: steadfastly maintain the red line for arable land while actively tapping into the potential for increased production of existing arable land resources. Strictly implement the "preserve land to stabilize grain" policy: first, firmly adhere to the principle that "farmland is farmland"; second, emphasize the standard that "farmland must be fertile land"; third, create demonstrations of "intelligent empowerment of fertile land". Enhance the "occupy the best and improve the best" management to ensure the stability of the quantity and quality of cultivated land. Focus on land leveling, soil improvement, and enhancing soil fertility, in conjunction with the utilization of water resources. Optimize the multiple cropping index of arable land, systematically advance the crop rotation and fallowing of grain fields, fully stimulating the vitality of arable land. Improve the sustainable utilization efficiency of cultivated land resources, optimize the structure of agricultural planting, and achieve sustainable agricultural development.

Ultimately, the improvement of economic conditions will inevitably enhance the self-sustaining and self-developing capabilities of the food production system, maintaining a consistent and stable efficiency in food production (Yi, 2008). In this article, the latent variable of economic development is constituted by three manifest variables: agricultural labor productivity, agricultural land productivity, and the proportion of agricultural spending in fiscal expenditures. Therefore, to enhance resource development, one can start by strengthening fiscal input to support the construction of high-standard farmland. Better support the construction of high-standard farmland and improve financing channels. Adopt a variety of measures such as investment subsidies, fiscal discounts, reward mechanisms, and cooperation between government and social capital. On one hand, reduce the cost of agricultural production, and on the other, attract more agricultural practitioners. Additionally, plans should be made to construct modern grain and oil agricultural production areas, equipped with remote monitoring information systems. Enhance intelligent equipment and improve services such as drying, storage, logistics, agricultural machinery, and agronomic techniques to increase agricultural output value. Furthermore, although economic development is one of the factors directly affecting food supply capacity security, it cannot function independently from technology and resources. The three are closely linked, and thus accelerating technological development and implementing better resource allocation methods can better enhance the role of economic development in promoting food supply capacity security.

(2) Social development and scientific and technological development have a negative impact on the security of food supply capacity.

Social development has exerted a direct negative impact on food security. This paper defines social development as a latent variable composed of three manifest variables: the Engel coefficient of rural households, the food consumption price index, and the consumption level index. Therefore, to transform this negative impact into positive effects and gradually enhance its beneficial role, the following measures can be taken: Encourage and support the establishment of partnerships between agro-social service entities and dispersed small-scale farmers to reduce planting costs. Simultaneously, the current farmland subsidy system should be improved to ensure the implementation of policies such as "subsidize as much as you plant" and "subsidies go to the cultivator". Furthermore, the implementation of policy-based grain insurance needs to be strengthened to stabilize farmers' enthusiasm for production and enhance their ability to withstand risks, thereby improving the efficiency and quality of grain production.

The current technological advancements have had a direct negative impact on the security of food supply capacity in Sichuan Province. This study considers technological development as a latent variable, which is composed of two manifest variables: the total power of agricultural machinery and the number of agricultural professionals. To transform this negative impact into positive effects and gradually amplify its positive influence, the following measures should be implemented: strengthen the support for subsidies on the purchase of agricultural machinery, increase the subsidy standards for machinery urgently needed in grain-producing areas, and continuously expand the coverage of subsidies; Increase investment in the "mechanization-friendly" transformation of sloped and valley areas. Proactively cultivate new professional farmers and agricultural vocational managers, and nurture local grain production experts. Encourage recent university graduates, agricultural technicians, rural entrepreneurs, and urban returnees to engage in the grain industry. Perfect the talent training system, assessment procedures, and precise talent-matching mechanisms for the grain industry to cultivate more professionals, promote high-quality development of the grain industry, and enhance the scientific management capabilities of agricultural workers.

The security of food supply capacity is not only about the maximum actual food reserves at a specific point in time but involves the combined effect of various influencing factors to ensure robust actual and potential food production capacity over an extended period (Zhou et al., 2015). This requires measures that promote the coordination and sustainable development of social, economic, technological, resource, and environmental aspects to systematically and comprehensively ensure the food supply security of Sichuan Province. For instance, urbanization may encroach on farmland and consume water resources (Huang & Zhang, 2023); thus, rational planning of the layout and scale of urban construction is necessary to prevent extensive occupation of farmland and reasonable utilization of water resources during urbanization to avoid waste and pollution, ensuring sustainable resource development. With well-coordinated economic and resource development, attention must also be paid to technological and environmental advancements. The overuse of cultivated land can lead to a decline in soil fertility and degradation; therefore, reasonable planning of crop rotation systems is necessary, along with promoting environmental protection and accelerating agricultural technological progress. This can reduce the use of chemical fertilizers and increase grain seeding rates and yields by promoting technologies such as soil testing and formulated fertilization, integrated water and fertilizer management, biological pest control, and precision medication, thus achieving a reduction in fertilizer and pesticide usage. Vigorously promote agricultural mechanization and the R&D of agricultural machinery equipment, enhance equipment performance, and develop professional services to facilitate the widespread adoption of advanced technologies, thereby improving seeding efficiency through mechanization. Actively promote superior varieties, including the cultivation and promotion of high-quality varieties of major crops, to increase the coverage of superior varieties (Wang, 2023). On the foundation of secured economic development, rational resource utilization, continuous progress in agricultural technology, and environmental protection, social development should also be valued, particularly in enhancing the sense of gain for those engaged in agriculture by improving technological support, cultivation resources, environmental benefits, and economic income for agricultural practitioners. This will attract more people to agriculture, increase the number and quality of agricultural workers, thereby promoting sustainable growth in grain production, and ultimately ensuring the security of the food supply.

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