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Exploring determinants of county suburban vegetable planting via the fsQCA-NCA approach

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Taking 26 county suburban areas of significant vegetable growers in Henan Province as a case study, this paper constructs a theoretical framework for market demand, market supply, and market environment on the basis of the conditions constraining the scaling up of vegetable production in county suburbs. Six indicators are selected to measure the vegetable planting scale in different counties/districts. Using fuzzy-set qualitative comparative analysis (fsQCA) and necessary condition analysis (NCA) methods, ten configurations are analyzed. The results show that the main paths for achieving large-scale vegetable production in county suburban areas rely primarily on market demand, followed by market environment. On the basis of these findings, to improve vegetable production levels in Henan Province, efforts should focus on aligning with the willingness of vegetable growers, enhancing both the soft and hard environments for vegetable production, and nurturing and introducing leading vegetable enterprises to build the vegetable industry chain. These measures will gradually promote the realization of large-scale vegetable production in county suburban areas.

KEYWORDS

county suburbs, configuration and paths, fsQCA, NCA, large-scale vegetable production

1 Introduction

The vegetable industry is a traditional agricultural industry in China and an important pillar in promoting rural economic development (Miao et al., 2021). The 19th National Congress of the CPC put forward the implementation of a rural revitalization strategy, pointing out that agriculture is the foundation of the national economy and that the rural economy is an essential part of the modernized economic system. As cash crops, vegetables occupy a pivotal position in the economic development of rural areas, and the development of the vegetable industry is highly important for promoting the development of the rural economy and the implementation of rural revitalization strategies (Miao et al., 2021). In recent years, the vegetable industry cluster phenomenon has been prominent, with growing trends toward centralization, regionalization, and specialization. This development plays a vital role in enhancing the agricultural economy of counties (Jiang and Pu, 2014). The development of the vegetable industry is also highly important for increasing the income of farmers and optimizing the dietary structure of both urban and rural residents (Zhu et al., 2020).

Henan Province is a major vegetable-producing area in China. Vegetables constitute the second largest crop in China and constitute a significant component of suburban agriculture around county towns. Henan is a leading province for vegetable production, ranking first in both vegetable planting area and vegetable output nationwide. China's total vegetable planting area was 22.434 million hectares in 2022, while that in Henan Province was 1.7525 million hectares (CSY, 2023), accounting for 7.81% of the national total and making Henan Province the largest provincial planting area in China. Similarly, China's vegetable output was 775.488

million tons in 2021, whereas that of Henan Province was 76.072 million tons (CRSY, 2022), accounting for 9.81% of the national total and making Henan Province the largest provincial output in China. Owing to its rich light and heat resources and convenient transportation, Henan Province is well suited for the year-round development of both greenhouse and open-field vegetable production. However, of the 580 Chinese large-scale vegetable-producing counties, Henan Province boasts only 26 such counties (NVIDP, 2011), accounting for only 4.48%; this is inconsistent with its vegetable production scale.

Moreover, smallholder vegetable production has several inherent limitations. For example, within the framework of the current rural basic management system, smallholder farmers will continue to be the mainstay of China's agricultural operations for a long period (Huang and Zhang, 2022). In vegetable production, smallholders typically operate in a family workshop style. Data from the Third National Agricultural Census show that the average operating scale for smallholders is 7.8 *mu* (approximately 0.52 hectares) per household. With changes in social productivity and development, especially the acceleration of new quality productivity, small-scale vegetable production can lead to high costs per unit area, directly affecting efficiency levels (Zhu et al., 2016; Jiang and Pu, 2014). Conversely, too large a scale can create burdens in terms of labor, capital and management, severely impacting the level of production management and resulting in inefficiency (Dai and Wu, 2019). In this context, modern factory-based intelligent production has emerged, allowing for the large-scale and standardized production of vegetables.

Large-scale suburban-county vegetable production still faces some challenges in Henan Province (Yu, 2014). The first challenge is a low level of industrialization (Yu, 2014; Zhang and Tang, 2021). Smallholder farmers intensively rely on household-based operations and thus lack effective organizational and intensive production methods (Huang and Zhang, 2022). This leads to low production efficiency (Shrestha et al., 2016), making it difficult to meet market demand and cope with market risk (Yang, 2008; Evelyne and Steven, 2014). The second challenge is poor market circulation (Ma, 2023). There is a weak connection between vegetable production and sales, leading most farmers to plant crops blindly due to a lack of effective market information and sales channels (Wang, 2023). Additionally, the lack of an efficient cold chain logistics system restricts the rapid cross-regional distribution of vegetables (Wang, 2023). The third challenge consists of insufficient deep processing capabilities (Xu, 2021; Zhu, 2015). Most county suburban areas lack enough vegetable processing enterprises, resulting in a significant amount of fresh vegetables being sold only as raw materials (Wu, 2020; Xu, 2021). Therefore, both deep processing and the development of high-value-added products are lacking (Wu, 2020). The fourth challenge is an incomplete market sales system. There is a lack of effective linkages between vegetable production and vegetable marketing (Yu, 2016), which reduces farmers' enthusiasm for large-scale production and hinders the further development of vegetable production bases (Zhang, 2021). Finally, the fifth challenge is that the production techniques need to be improved (Ceng, 2023; Yu, 2016; Chepkoech et al., 2020; Ochieng et al., 2022).

Importantly, China is currently implementing a rural revalidation plan by prioritizing the development of a county-level economy (Si and Cao, 2022; Sun and Xing, 2024). In fact, the Chinese administrative management system consists of countries, provinces and counties. A county is usually a relatively independent jurisdictional area; therefore, it is important to develop a county economy, especially to achieve a rural revalidation plan (Liu and Han, 2019; Zhang, 2022). Thus, as a result of the abovementioned rural revalidation plans and the development of county-level economies, a large and growing rural population is expected to remain in the county (Chen et al., 2021; Kong and He, 2022), which will strongly drive the development of the county-level nonstaple food sector, including the vegetable supply (Su, 2023). Therefore, it is time to design a configuration and identify a pathway for the development of county-level suburban vegetable production.

To address these issues, there should be a focus on developing the vegetable sector in terms of branding, technology, specialization and commercialization (Miao et al., 2018). Large-scale vegetable production in suburban counties is worthy of research and represents a clear national strategic direction. However, many studies on large-scale, county-scale, suburban vegetable production are predominantly macro descriptive and lack qualitative research. Thus, there is a great societal need to find context specific, clear, high-quality, and efficient methods to promote large-scale county suburban vegetable production in Henan Province.

This paper aims to construct a theoretical framework for market demand, market supply, and market environment on the basis of the conditions constraining large-scale county-level suburban vegetable production. By employing the fsQCA and NCA approaches, this paper aims to identify the configuration and path for large-scale county-level suburban vegetable production in Henan Province.

2 Literature review

As important functional foods, vegetables are the primary food used to satisfy people's nutritional balance and daily diet (Fan et al., 2012). However, there are still many problems present in the county-level vegetable industry in terms of production, circulation and sales (Zhao et al., 2022). First, owing to low-level and backward scientific and technological innovation, it is difficult to lead the development of modern agriculture (Li C. et al., 2024). Second, the vegetable base is small in scale and boutiqueless, the grade is not high, and the quality of vegetables, varieties and regionalization level are still difficult to determine (Pu et al., 2011). Third, the infrastructure is not sufficient to improve the modernization of vegetable production facilities, such as by supporting sprinkler drip irrigation, the fumigation of chemicals and other obvious shortcomings (Jiang and Pu, 2014). Fourth, owing to the lack of scientific and technological personnel, farmers do not have a good grasp of such information, making it impossible to improve vegetable processing in detail (Li H. Y. et al., 2024). Fifth, the vegetable production process is not easy to control, the production technology level is low, and the production effect is poor (Zhu et al., 2016).

Vegetable production is sensitive to climate change in China. Zhai et al. (2021) revealed the effect mechanism of daily rainfall on vegetable prices. It has been argued not only that daily excess precipitation under certain conditions has a positive effect on vegetable prices but also that the impact of precipitation on vegetable prices is significantly heterogeneous over different time scales, in which the impact effect on the daily scale is more sensitive, and that the impact effect on the monthly scale has a significant lag and is not strong in persistence. Touili et al. (2024) explored the impact of precipitation on vegetable prices on the basis of a case study in the Paris region to explore what vegetable farmers expect from climate services by 2060 to help them adapt to climate change. Chepkoech et al. (2020) analyzed the adaptive capacity of vegetable smallholders to climate change in Kenya.

Fertilizer and pesticide use is often criticized in vegetable production. Zhou and Ma (2024) investigated the influence pathway and degree of green fertilizer and pesticide application on vegetable production and reported that government-embedded external factors and farmers' internal perceptions have different degrees of influence on their green production behavior. Wan and Mu (2024) empirically analyzed the driving effect of social capital and explored the heterogeneity of social capital to measure the elasticity of the substitution of organic fertilizers and chemical fertilizers. Bolfarici et al. (2024) validated the role of the market in incentivizing farmers to reduce pesticide use. Zhao et al. (2018) studied vegetable farmers' behavior toward pesticide application and explored the factors influencing the perceived quality and safety premiums of agricultural products.

Therefore, the adoption of green technologies is always welcomed in vegetable production. Luo and Sun (2023) examined the impact of internet use on farmers' adoption of green vegetable technologies. They argued that internet use can significantly increase the intensity of green vegetable technology adoption. Zhang and Li (2023) analyzed the factors influencing the adoption of green production technologies and suggested that green production technology can significantly increase the income of farmers. Specifically, Xiong et al. (2021) analyzed the impact of green certification on the adoption of green prevention and control technologies and concluded that green certification significantly promotes the adoption of these technologies. Nevertheless, the coverage of green certification is not yet high and needs to be further promoted. Yang C. F. et al. (2021) evaluated the economic effects of five fertilizer reduction and efficiency technology models for greenhouse vegetables in cold regions. Ma et al. (2022) analyzed the effects of social networks and internet use on farmers' green production technology adoption behavior and their interaction. Li L. L. et al. (2024) studied the impact of e-commerce participation on the green production behavior of greenhouse vegetable farmers. Ochieng et al. (2022) suggested that sustainable agricultural technologies can have a positive impact on crop yields. Zhao et al. (2022) and Li et al. (2022) examined the dynamics of farmers adopting sustainable agricultural technologies and the factors influencing farmers' technology choices.

Moreover, increasing technical efficiency is important in vegetable farming. Yan and Zheng (2021) empirically tested the impact of internet use on the production efficiency of household vegetable production and reported that internet use can significantly improve production efficiency. Zhang (2018) conducted a study to investigate the vegetable production efficiency of households with different vegetable cultivation scales and reported that large-scale farmers are more efficient than small-scale farmers. Wang et al. (2021) used cucumber and tomatoes as examples to analyze the production efficiency of Chinese greenhouse vegetables. Shrestha et al. (2016) assessed the economic efficiency of vegetable farms in Nepal and concluded that vegetable farms in Nepal have considerable potential to improve the efficiency of vegetable production. Li and Lu (2020) empirically tested whether three different product quality certifications can improve the technical efficiency of vegetable farmers. Li et al. (2019) explored the impact of the industrial organization mode on the technical efficiency of vegetable production.

Similarly, environmental efficiency is also important in vegetable production. Yan and Mu (2024) measured the ecological efficiency of vegetable farmers in five provinces and cities in Beijing, Tianjin, Hebei, Shandong and Liaoning and reported that production services can significantly improve and have a more pronounced effect on high ecological efficiency. Xu and Mu (2020) investigated the dynamic evolution characteristics and driving mechanism of the ecological efficiency of greenhouse vegetable production.

It is highly important for vegetable farmers to increase their income. Zhang and Mu (2018) explored the mechanism and spillover effect of industrial agglomeration of vegetable specialty villages on farmers' income in local and neighboring towns. Su et al. (2022) investigated how organic fertilizer substitution affects the income of vegetable farmers. Yang S. et al. (2021) studied the welfare effect of farmers' information literacy on vegetable farmers and the food safety of vegetable production. Ha et al. (2019) investigated the differences in the willingness to purchase organic vegetables between urban and rural residents in Vietnam. Ha et al. (2020) studied the determinants of vegetable risk perception in rural and urban areas and the effect of risk perception on vegetable consumption in Hanoi, Vietnam.

Vegetable import and export trade is a driver of vegetable production. Wan and Xu (2024) explored the evolutionary characteristics and factors influencing China's vegetable export pattern in detail. Liu et al. (2018) chose the explicit comparative advantage index and trade competitiveness index analysis methods to carry out scientific evaluations and international comparisons of the global competitiveness of China's vegetable exports. Li Q. H. et al. (2024) constructed a spatial Durbin model to explore the spatial correlation and spillover effect of China's spicy vegetable export trade. Li et al. (2023) analyzed China's trade in vegetables with "Belt and Road" partners through data comparison. Liu et al. (2023) explored the impact of the Russia–Ukraine conflict on fluctuations in the European vegetable market and China. Zhu et al. (2020) used Jiangsu Province as an example to analyze the spatial heterogeneity of the comparative advantage of vegetable production and its historical evolution. Zhang et al. (2020) conducted spatial, statistical and econometric analyses to reveal the spatial and temporal divergence characteristics of vegetable production patterns in the Beijing-Tianjin-Hebei region.

Vegetable distribution is a crucial circulation chain for consumers. Mu and Lai (2021) studied the impact of livelihood capital on vegetable intermediary purchases, self-delivery to the wholesale market of the place of origin, sales in the local farmer market, and other channels and concluded that improving the vegetable circulation information exchange platform is necessary. Zhang et al. (2018) took vegetable circulation from Shouguang in Shandong to Beijing as an example to systematically analyze the structure, behavior and performance of the vegetable wholesale industry. Zhou (2019) used a joint evaluation model to explore urban vegetable circulation terminal selection preferences.

The creation of vegetable brands is a key innovation in vegetable industry development. Hu et al. (2018) explores and analyzes the dilemma of branded vegetable development. Zhang et al. (2021) empirically analyzed the main factors affecting the brand-building behaviors of vegetable professional cooperatives. Feng et al. (2022) empirically investigated the forms of production organization, seedling service needs and dilemmas of China's vegetable growers to explore China's vegetable factory seedlings in optimizing the industrial layout and changing the docking mode.

While there are many studies on vegetable production, there are few studies on county-level vegetable production and relevant aspects in China. Therefore, this paper focuses on county-level, large-scale, macrolevel, vegetable production policies.

3 Methods and procedures

Fuzzy-set qualitative comparative analysis (fsQCA) combines social science thinking with fuzzy mathematics methods to form a relatively stable research paradigm (Ragin, 1987). First, the research topic is determined, followed by the selection of specific cases and the identification of outcome conditions and causal conditions (Ragin and Amoroso, 2011). The identification of causal conditions can be based on a theoretical framework to ensure the theoretical and logical relationships between variables (Greckhamer et al., 2018). This step is the same as that used in regression analysis, with one or two (not excluding multiple) outcome conditions and generally 4–8 causal conditions (not excluding more). The variables are assigned values to form the raw data, which is the same process as that used in regression analysis.

In qualitative comparative analysis, *qualitative* analysis is relative to quantitative analysis. First, the nature of the independent variables, i.e., the causal conditions or conditions that lead to the outcome, is determined, which involves both the relationship between a single independent variable and the outcome and the relationship between variable combinations and the outcome condition (Furnari et al., 2018). Next, comparisons among multiple sets of relationships involve a mathematical relationship analysis to determine the membership relationship between different condition combinations (configurations) and the outcome (Ragin, 2014; Park et al., 2020).

Qualitative comparative analysis requires first transforming and processing the raw data. In fuzzy sets, standardization is not simply a normalization calculation but involves calibrating the dataset into "membership" and "nonmembership" sets (Thiem, 2014). Next, the data are calibrated into sets between 0 and 1, called membership functions. The third step calculates the consistency coefficient for each causal condition, with values greater than or equal to 0.9 considered necessary conditions. The membership values are used to create a truth table and construct a 2^k-dimensional vector matrix for standardized analysis, setting thresholds for consistency and PRI that are usually not lower than 0.8 and 0.75, respectively, with values above 0.5 being theoretically acceptable. The fourth step is to conduct specific or standardized analyses with at least one condition, namely, a PRI threshold not lower than 0.5, to obtain configuration solutions. Standardized analysis is generally adopted, combining identified necessary conditions (if any) to obtain complex, parsimonious, and intermediate solutions, along with their respective consistency and coverage coefficients. The parsimonious and intermediate solutions are merged to identify both core and peripheral conditions, selecting the final effective configuration for robustness testing and explaining the research topic and cases on the basis of the configuration (Rihoux and Ragin, 2009).

QCA analysis, as a paradigm, has strict procedures starting with variable selection, using fuzzy mathematics set processing and the Quine-McCluskey algorithm to simplify Boolean expressions, ultimately obtaining three types of solutions and their consistency and coverage coefficients (Furnari et al., 2021).

3.1 Selecting outcome conditions and cases

The research topic of this paper is counties with significant vegetable production, with the outcome condition being the production scale of these counties. The analysis uses 26 major vegetable-producing counties in Henan Province as cases. Setting S_O as the set space of the result condition, O^w is a concrete result condition (Mendel and Korjani, 2013). Thus, we have the following:

$$S_O = \left\{O^w, w = 1, \ldots, n_O\right\} \tag{1}$$

Different outcome conditions are independent of each other, and there are also strict boundaries. For example, different cases can be divided into multiple levels according to their development level, which are typically divided into "high-level" and "nonhigh-level" in the literature. All the cases constitute a finite space S_{Cases}, and if there are any cases N, then their spatial set is as following Equation 2:

$$S_{Cases} = \{1, 2, \ldots, N\} \tag{2}$$

3.2 Selecting causal conditions

Choosing appropriate causal conditions is crucial for QCA analysis. Unlike linear regression analysis, QCA involves the configuration analysis of causal conditions. With *n* conditions, there are 2^n combinations. When the number of cases is limited, numerous logical remainders exist. The selection of causal conditions must have a strict theoretical and logical relationship with the outcome conditions, generally on the basis of a rigorous theoretical framework, to ensure that the causal conditions both comprehensively and importantly explain the outcome.

Let $S_{C'}$ be the set of all causal conditions. Then, we have the following Equation 3:

$$S_{C'} = \{C'_{i'}, i' = 1, \ldots, n_{C'}\} \tag{3}$$

Specific causal conditions are selected in this set to form a S_C of all causal conditions or a set of causal condition variables. Thus, there is the following:

$$S_C = \{C_i, i = 1, \ldots, k\} \ni \forall C_i \in S_{C'} \tag{4}$$

3.3 Determining membership functions

In defining the criteria for determining the membership relations of the outcome and causal conditions in Equations 1 and

4, fixed membership standard values can be adopted, i.e., 0.95 for high membership, 0.05 for high nonmembership, and 0.5, to serve as the thresholds between membership and nonmembership. Alternatively, the critical values for different degrees of membership can be determined on the basis of the characteristics of the original data from Equations 5 and 6:

$$u_0 : \Omega \subseteq \mathbb{R} \rightarrow [0,1]\, \omega \mapsto u_0(\omega) \tag{5}$$

$$u_{c_i} : \begin{cases} \Xi_i \subseteq \mathbb{R} \rightarrow [0,1] \\ \xi_i \mapsto u_{C_i}(\xi_i) \end{cases} i = 1, \ldots, k \tag{6}$$

The original data are calibrated according to the membership criteria to obtain the results, and membership functions are derived for each item as shown by Equations 7 and 8:

$$u_O^D : \begin{cases} (S_{Case}, S_O) \rightarrow [0,1] \\ x \mapsto \omega(x) \mapsto u_o(\omega(x)) \equiv u_O^D(x) \end{cases} \tag{7}$$

$$u_{C_i}^D : \begin{cases} (S_{Case}, S_c) \rightarrow [0,1] \\ x \mapsto \xi_i(x) \mapsto u_{C_i}(\xi_i(x)) \equiv u_{C_i}^D(x) \end{cases} \tag{8}$$

3.4 Identifying necessary conditions

The consistency coefficient and coverage for the variable and its complement are computed. A consistency coefficient of 0.9 identifies the condition as necessary, marking it as "present" in the subsequent standardization analysis. The formulas for consistency and coverage are shown in Equations 9 and 10 (Mendel and Korjani, 2018):

$$\text{Consistency}\left(u_{C_i}^D(x) \leq u_O^D(x)\right) = \frac{\Sigma\left(\min\left(u_{C_i}^D(x), u_O^D(x)\right)\right)}{\Sigma\left(u_{C_i}^D\right)} \tag{9}$$

$$\text{Coerage}\left(u_{C_i}^D(x) \leq u_O^D(x)\right) = \frac{\Sigma\left(\min\left(u_{C_i}^D(x), u_O^D(x)\right)\right)}{\Sigma u_O^D(x)} \tag{10}$$

In Equations 9 and 10, $u_{C_i}^D(x)$ and $u_O^D(x)$ represent the sets of membership scores for the variables and the outcome condition, respectively. $u_{C_i}^D(x) \leq u_O^D(x)$ indicates that the variable is a subset of the outcome. Consistency is the ratio of the subset condition membership to the total membership score. The closer this ratio is to 1, the more confidently the condition set belongs to the outcome set. A ratio of at least 0.8 indicates a sufficient condition, and a ratio of 0.9 or higher is considered a necessary condition. Coverage modifies the denominator of consistency to the sum of the outcome membership scores, indicating the extent to which the condition explains the outcome. The ratio ranges from 0 to 1 and generally has no specific requirements.

3.5 Constructing the truth table and standard analyses

The membership values of the variables are converted to 0 and 1 on the basis of the crossover threshold, forming a 2^k-dimensional vector matrix. Rows with missing instances and consistency coefficients below 0.8 are removed, and a PRI threshold is set to further delete nonconforming rows. Standard analyses are then conducted to obtain complex, parsimonious, and intermediate solutions, as well as consistency coefficients and coverage for each solution. The computational principles of the model can be found in Mendel and Korjani (2012) and Mendel and Korjani (2013).

3.6 NCA analysis method and steps

Necessary condition analysis (NCA) is a method used for identifying conditions that are indispensable for the occurrence of a specific outcome. Without these conditions, the outcome cannot occur. This analysis method was proposed by Professor Jan Dul from the Rotterdam School of Management in 2016.

Dul (2016a,b) offered an example to illustrate the concept and importance of necessary conditions; i.e., for a student to be admitted to a graduate school in the U.S. (outcome condition), a high GRE score is needed. Without it, no matter how good the other conditions are, they will be irrelevant. In this context, the GRE score is a necessary condition. However, it alone does not guarantee admission; other conditions related to academic performance, such as undergraduate grades and the university attended, are also necessary. A necessary condition is a threshold or bottleneck; other conditions can only take effect on the basis of this condition.

NCA quantitatively demonstrates the level of necessary preconditions required to achieve a certain outcome level by analyzing the effect size and bottleneck level of causal conditions. It effectively complements traditional sufficiency analysis techniques.

The data used for NCA should be consistent with the data calibrated for QCA. NCA analysis can be divided into two types: ceiling regression (CR) and ceiling envelopment (CE). Generally, both calculations are performed. CR is used for analyzing continuous variables and discrete variables with more than five categories, whereas CE analyzes dichotomous variables and discrete variables with fewer than five categories.

NCA examines necessary conditions. However, in configurational analysis papers, the purpose of NCA is to verify that none of the variables are necessary conditions for the outcome variable. If all the variables are identified as nonnecessary conditions, then the NCA requirements are considered to have been met. Nonnecessary conditions are defined as having an effect size<0.1 or a significance level > 0.01.

4 Theoretical framework and sample size

4.1 Theoretical framework

Vegetable production is constrained by various factors, such as natural conditions, social and economic infrastructure, technological levels, and living traditions. Some key constraints, such as natural conditions, may be negligible if cases are selected within the same area. Similarly, the homogeneity of technical environments and dissemination within the same region are not considered constraints for the large-scale development of vegetable production.

Examining the major vegetable-producing counties in Henan Province reveals that all 26 counties are located on the *Huang-Huai-Hai* Plain and have similar geographical and climatic conditions. None of the major vegetable-producing counties are found in the western *Taihang* Mountains, *Funiu* Mountains, or southern *Dabie* Mountains. The development trajectory of these vegetable-producing counties shows both regularity and contingency. First, the emergence of vegetable-producing counties is a natural process that occurs mainly in the suburbs of large cities and neighboring counties. As cities expand, they spawn nearby vegetable production bases; however, urban expansion eventually engulfs these bases, pushing the vegetable-producing counties further outward. Second, vegetable-producing counties are not naturally formed. Vegetable production bases can also emerge on the outskirts of large cities, where modern transportation blurs the boundary between suburban and outer suburban areas. Outer suburban areas often have lower production costs and larger land scales and are conducive to large-scale vegetable production. Moreover, remote counties face significant constraints in industrial structure adjustment, with governments preferring developing high-economic-benefit vegetable production.

On the basis of the theoretical analysis, the following conclusions can be drawn. (i) The formation of major vegetable-producing counties is market driven; proximity to consumer markets favors vegetable production and sales. (ii) With urban expansion and modernized transportation, the advantages of vegetable production in remote suburbs become apparent, allowing for both local supply and distant sales. (iii) Traditional agricultural counties, or counties with large arable land and wheat production, are more likely to transition to major vegetable-producing counties during industrial structure optimization, with government guidance and a favorable economic environment crucial for vegetable industry development.

In summary, large-scale vegetable production is constrained by three conditions, namely, market demand, market supply, and public services. In a natural economy, farmers produce vegetables for self-consumption, with a small portion for sale. The emergence and growth of cities create market demand, leading to specialized vegetable farming for market sales, resulting in large-scale production. Larger scales reduce costs and increase market competitiveness. In modern society, with increasing urbanization and improved living standards, both urban and rural residents purchase vegetables, meat, and other nonstaple foods from the market. Currently, even wheat farmers purchase their food from the market. While the increasing demand for vegetables due to urbanization and improved living standards has created a market supply, not all regions have become vegetable production bases. Large-scale vegetable production requires close cooperation among farmers, enterprises, and the government. The government must plan and provide technical training, relevant enterprises must establish market channels for standardized and commercialized vegetable production, and farmers should comply with governmental planning and requirements for orderly competition. The key to large-scale vegetable production in a county is supply-side management. On the basis of the constraints placed on large-scale vegetable production, a three-dimensional theoretical framework (Figure 1) is constructed with reference to the relevant literature (Tang et al., 2023).

Among the three dimensions determining the scale of vegetable production, market demand is an objective existence, whereas market supply is subjectively created by three key stakeholders, namely, farmers, traders and the government, or more precisely, the government, enterprises and farmers. In this context, farmers and enterprises are both parties in market transactions, aiming to gain economic benefits. The government, on the other hand, plays the role of providing public goods, such as technical guidance, infrastructure provision and maintenance, and market regulation, in these transactions. In such market transactions, the level of informatization significantly influences transaction costs. Although the informatization levels vary across regions in Henan Province, the impact on vegetable transactions is negligible. Approximately 95% of rural areas have achieved fiber-optic household access, and 4G and 5G wireless networks are nearly universal. Especially in vegetable production regions, informatization conditions are fairly uniform and do not constitute a variable affecting vegetable transactions.

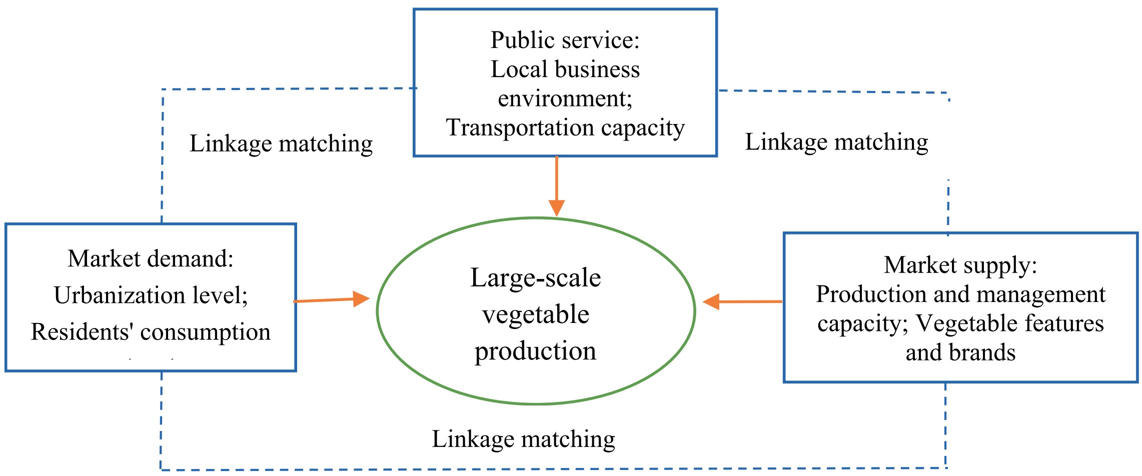

FIGURE 1
Three-dimensional theoretical framework.

The scale of vegetable cultivation is not necessarily better when it is larger. Within a certain period and region, the market capacity for vegetables is fixed. Owing to the perishable nature of vegetables and high refrigeration costs, excessive cultivation or the overproduction of a particular vegetable inevitably leads to the phenomenon of "inexpensive vegetables harming farmers." Several factors influence the scale of vegetable cultivation, with land area being the most decisive. Suburban areas typically have less farmland, and urban expansion encroaches on arable land, reducing production scales. In more distant suburbs, vegetable cultivation is limited by national wheat production policies. Taking Henan Province as an example, the vegetable cultivation areas in various counties and cities are currently stable, and both increasing facility-based vegetable cultivation and expanding open-field vegetable cultivation present particular challenges.

In conclusion, within a specific region, the natural climate, land system, and cultivation technique are not limiting factors for vegetable cultivation scale. The differences in vegetable production scales across regions are determined mainly by market demand and public services. First, market demand dictates the upper limit of vegetable production, with different regions having distinct market demands, determining the local structure and scale of vegetable cultivation. As the market scope expands and markets unify across regions, the competitiveness of vegetable production in different areas determines their respective scales and levels. While many factors affect the competitiveness of vegetable production, the main factors are production and transaction costs. Production costs tend to equalize in competition, whereas transaction costs, which are influenced by geographical location and the market environment, are challenging to balance in competition. Second, the organization and supply of vegetable production require a certain organizational framework for scale cultivation and transactions. This includes farmer production organizations to ensure consistency in production specifications and technical standards, vegetable sales organizations to ensure smooth acquisition and sales channels, vegetable processing organizations to ensure value addition and benefits for growers, and vegetable industry associations to establish and maintain vegetable brands and local characteristics, providing technical guidance and supervision. Finally, the market transaction and production environment, which is primarily the government's responsibility, includes ensuring the implementation of national policies, fostering healthy market transactions, and maintaining good conditions such as transportation infrastructure. Generally, regions with better economic and social development also have better market environments.

4.2 Sample size

Several indicators can be used to measure the level of large-scale vegetable production, and for case analysis, a specific scope must be set, which is referred to as the sample size. The sample size selection should meet the following criteria: (i) a moderate size to ensure that the number of cases is neither too large nor too small; (ii) comparability to ensure differentiation among cases, facilitating comparative analysis; and (iii) alignment with actual economic and social development, avoiding arbitrary case selection. On the basis of these requirements, this study uses counties (or districts/cities) as the unit of analysis. Counties are the basic units for rural revitalization and coordinated urban–rural development in China and are the fundamental units for national economic and social statistics. Various advanced indicator assessments, such as wheat production, vegetable production, and top economic performance, use counties (districts/cities) as basic units. Henan Province has 26 major vegetable-producing counties, providing an appropriate sample size suitable for quantitative comparative analysis.

5 Variable selection

According to the abovementioned theoretical framework, the factors influencing the scale of vegetable production can be divided into three aspects, namely, the market demand level, the market supply level, and the public service level, with two specific causal conditions being set for each aspect.

For market demand, the primary consideration is local market demand, which is represented by the urbanization rate and residents' consumption levels. The urbanization rate (CZHL) indicates that a higher rate means fewer rural residents and greater demand for vegetable commodities. Many indicators can be used to measure resident consumption levels; this study uses *per capita* social retail sales (RJLS) of consumer goods, where a higher *per capita* purchasing power corresponds to a greater demand for vegetables and other byproducts.

For market supply, considering the actual situation of the cases, two indicators are chosen, namely, the level of vegetable organization and vegetable quality. The level of organization is measured by the number of vegetable enterprises (SCQYs), including vegetable cooperatives, logistics, processing enterprises, and sales enterprises. The quality of vegetables is measured by the number of vegetable brands (SCPPs) applied for by each county or city, including green vegetables, organic vegetables, and geographical indications.

For the market environment, it is assumed that the more developed the local economy is, the higher the level of public services provided by the government is, and the better the business environment is. Thus, *per capita* fiscal budget revenue (CZSR) is used as an indicator to measure the comprehensive service level. For the infrastructure provided by the government, the number of highway stations (GSLK) is chosen as the measure, indicating that vegetable cultivation relies not only on local markets but also on achieving external sales. Convenient traffic conditions are crucial, with more highway exits facilitating more accessible external transportation and promoting vegetable industry development.

Finally, determining the outcome conditions involves several indicators that measure the scale of vegetable cultivation, such as the planting area, production scale, and transaction scale. These are absolute values and are unsuitable for comparisons across different regions. For example, even with dispersed planting, the total scale in a county with large populations and arable land will exceed that of a smaller county. Therefore, to objectively measure production levels, both absolute and relative scales must be considered. This study uses relative indicators, with all cases identified as major vegetable-producing counties meeting specific standards. Thus, indicators such as the proportion of the vegetable planting area to the wheat planting area (SCDX) are used to measure the scale of vegetable cultivation across different counties and cities.

6 Data collection and calibration

6.1 Data collection

The areas of vegetable and wheat cultivation are publicly available statistical data, which, after comparison and analysis, are found to have remained relatively stable in recent years. Thus, the latest available data for 2022 are used. The urbanization rate for each county is calculated on the basis of 2022 data drawn from official statistics. The *per capita* retail sales of consumer goods are derived from the latest 2022 statistics. The second set of variables, including the number of vegetable enterprises in 2022 for each county, is sourced from data provided on the *Tianyancha* website in December 2023. The levels of green, organic, and geographical indications of vegetable brands in 2022 for each county are obtained from data provided on the National Market Supervision Administration website in December 2023. The third set of variables, including county-level fiscal budget revenues, the permanent population and the number of highways, is based on 2022 year-end data drawn from the Henan Statistical Yearbook (2023).

6.2 Measurement and calibration

The collected raw data are carefully verified to ensure accuracy and then calibrated via Excel. Before conducting fsQCA standardization analysis, data processing and handling are required to ensure uniform data formats and standards (Duşa, 2019). Calibration baselines for fsQCA analysis often use (0.95, 0.5, 0.05) to maintain the distinction in outcome conditions. Given that all the cases in this study are major vegetable-producing counties with inherently limited differentiation, the calibration baseline of (0.75, 0.5, 0.25) is chosen after multiple adjustments and comparisons to ensure that each configuration path effectively explains the cases (Nikou et al., 2022; Pappas and Woodside, 2021). The specific calibration values and descriptive statistics for the raw data are provided in Table 1.

7 Analysis and examination

7.1 Identifying necessary conditions

In qualitative comparative analysis (QCA), the relationship between qualitative causal conditions and outcome conditions is crucial. A condition is necessary if its presence is required for the occurrence of the outcome. In configuration analysis, a condition is necessary if it appears in all configurations leading to the outcome. The identification of necessary conditions is a significant feature of QCA. Traditional multiple regression analysis does not distinguish between such causal relationships and treats all variables as having a quantitative relationship with the outcome without determining the existence of a qualitative relationship (Du et al., 2021).

In QCA, the consistency between causal and outcome conditions is typically used as the criterion for identifying necessary conditions (Parente and Federo, 2019). However, consistency coefficients have limitations, as they are qualitative judgments and do not specify the probability or degree to which the outcome depends on the necessary condition. To address this limitation, NCA is often used to aid in the identification of necessary conditions (Dul, 2016a, 2016b). The combination of both methods enhances the meaningfulness and value of fsQCA analysis (Du et al., 2021; Vis and Dul, 2018).

First, the necessity of causal conditions is analyzed via fsQCA31b. Table 2 shows that in the category of "high-level vegetable production counties," the highest consistency value is for RJLS at 0.7582, with a corresponding minimum value for nonper capita retail sales (~RJLS). This indicates the importance of this indicator in the formation of vegetable counties; however, it does not meet the standard of a necessary condition. Further examination of the data for the second "non" set does not reveal any causal conditions with consistency greater than 0.8. Therefore, no single condition is found to be indispensable for the formation of high-level vegetable counties; i.e., there are no necessary conditions.

Therefore, further examination via the NCA method is conducted to determine if there were any necessary conditions (Acquah, 2024). To do so, the R language is used to activate the NCA package (Cangialosi, 2023), and scatter plots are created for each causal condition relative to the outcome condition by using the following code:

```
data <-read.csv("C:\\Users\\XXX\\Desktop\\xxx.csv")
> data <-read.csv("C:\\Users\\XXX\\Desktop\\xxx.csv",header=FALSE)
> model<-nca_analysis(data,c(1,2,3,4,5,6),7)
> nca_output(model, plots=T)
```

The scatterplot obtained is shown in Figure 2.

Figure 2 clearly shows that the CE-FDH line leaves a blank area in the upper left area, indicating that the outcome condition is constrained by the causal conditions to some extent. The larger the blank area is, the stronger the constraint is, which is identified as a necessary condition when it reaches a certain level. Among the six causal conditions, the largest blank area is for *per capita* social retail sales (RJLS), followed by *per capita* local fiscal budget revenue (CZSR) and the urbanization rate (CZHL). The other three conditions, namely, SCQY, SCPP and GSLK, have almost no blank areas left, suggesting that the first three conditions may be necessary conditions. We further input the following code:

```
model<-nca_analysis(data,X,Y,ceilings="cr_fdh", test.rep=10,000)
nca_output(model, test=TRUE)
```

where X refers to the causal condition and Y refers to the result condition. In this paper, the result condition is shown in Column 1, with Y values of 1 and X values of 2--7. cr_fdh indicates the analysis that uses the CR technique. Test.rep = 10000 indicates that the number of redraws is 10,000. The analysis results are shown in Table 3.

The effect size measures the minimum level of a necessary condition required to produce a specific outcome, ranging from 0 to 1. The closer the value is to 1, the greater the effect size is. Values of less than 0.1 indicate a negligible effect size. The NCA package can use CR to analyze continuous and discrete variables with more than five levels and use ceiling envelopment (CE) to analyze binary and discrete variables with fewer than five levels. Different analysis techniques can be selected on the basis of the data characteristics, or

TABLE 1 Set, calibration, and descriptive statistics.

	Fuzzy set calibration			Descriptive analysis			
Set	Full membership	Crossing point	Completely unaffiliated	Mean value	Maximum value	Minimum value	Standard deviation
SCDX	287.27	184.96	144.74	486.24	6200.00	78.50	1183.27
CZHL	52.40	46.70	41.33	46.52	74.60	29.10	9.50
RJLS	20164.70	14751.95	12880.83	17010.94	38105.17	7827.51	6643.74
SCQY	3554.75	2646.00	1969.50	3268.54	10159.00	592.00	2296.39
SCPP	37.50	30.00	20.25	30.31	69.00	3.00	16.64
CZSR	2104.67	1769.95	1550.88	2341.85	7609.31	961.95	1524.82
GSLK	4.00	2.00	1.00	2.65	6.00	1.00	1.55

TABLE 2 Necessity test of individual conditions by fsQCA.

Causal condition	High-level large vegetable-producing counties		Nonhigh-level large vegetable producing counties	
	Consistency	Degree of coverage	Consistency	Degree of coverage
CZHL	0.5788	0.6117	0.4135	0.4493
~CZHL	0.4789	0.4427	0.6426	0.6107
RJLS	0.7582	0.7386	0.3111	0.3116
~RJLS	0.2933	0.2928	0.7390	0.7586
SCQY	0.5023	0.4820	0.5683	0.5606
~SCQY	0.5421	0.5498	0.4750	0.4953
SCPP	0.3861	0.3982	0.6229	0.6605
~SCPP	0.6708	0.6338	0.4325	0.4200
CZSR	0.5390	0.5223	0.5288	0.5268
~CZSR	0.5117	0.5137	0.5205	0.5372
GSLK	0.6100	0.5412	0.5781	0.5273
~GSLK	0.4672	0.5186	0.4970	0.5671

both the CR and the CE results can be reported to compare the robustness of the findings. According to the criteria provided by Dul et al. (2020), the effect size (d) of a necessary condition must be greater than 0.1 and statistically significant ($p < 0.01$).

Table 3 shows that the effect size (d) of only RJLS is greater than 0.1, and the variable's p value is less than 0.01, which means that it meets the criteria for a necessary condition. However, its effect size is less than 0.3, indicating a relatively minor influence on the occurrence of the outcome, making it a less critical necessary condition. Therefore, in the identification of necessary conditions by QCA consistency, lowering the consistency value to 0.75 also identifies RJLS as a necessary condition. In subsequent configuration analysis, if RJLS is absent from the configuration, it should be included as one of the configuration conditions.

To further analyze the relationship between the causal condition and the result condition, a bottleneck level test is carried out. The bottleneck level (%) refers to the level that reaches the maximum observation range of the result and the level value (%) that needs to be met within the maximum observation range of the causal condition. The bottleneck level analysis code is as follows:

```
model<- nca_analysis (data,c(X1: XN), Y)
nca_output(model, summaries=FALSE, bottlenecks=TRUE)
```

where X1: XN represents the range of the causal condition, which is the number of columns through the NTH column, and Y represents the result condition. The corresponding code is entered according to the column in which the result and causal conditions are located in the data. Columns 2 to 7 of these data are listed as causal conditions, and the first is listed as result conditions, that is, input "model < – nca_analysis (data,c(2:7), 1)." The operation results are shown in Table 4.

Table 4 shows that the three causal conditions, namely, CZHL, RJLS, and CASR, have bottleneck level constraints, whereas the other causal conditions do not have such constraints. To achieve a 90% level of high vegetable production counties, the bottlenecks for these three causal conditions are 27.7, 50.3, and 24%, respectively, with RJLS having the highest threshold, requiring a level of 50.3%.

7.2 Configuration analysis

Using QCA analysis software for configuration analysis, the consistency threshold is set at 0.8, and the PRI value is set at 0.75 (An et al., 2020), with no less than one case explained. For counterfactual analysis, the option "present or absent" is selected. The complex

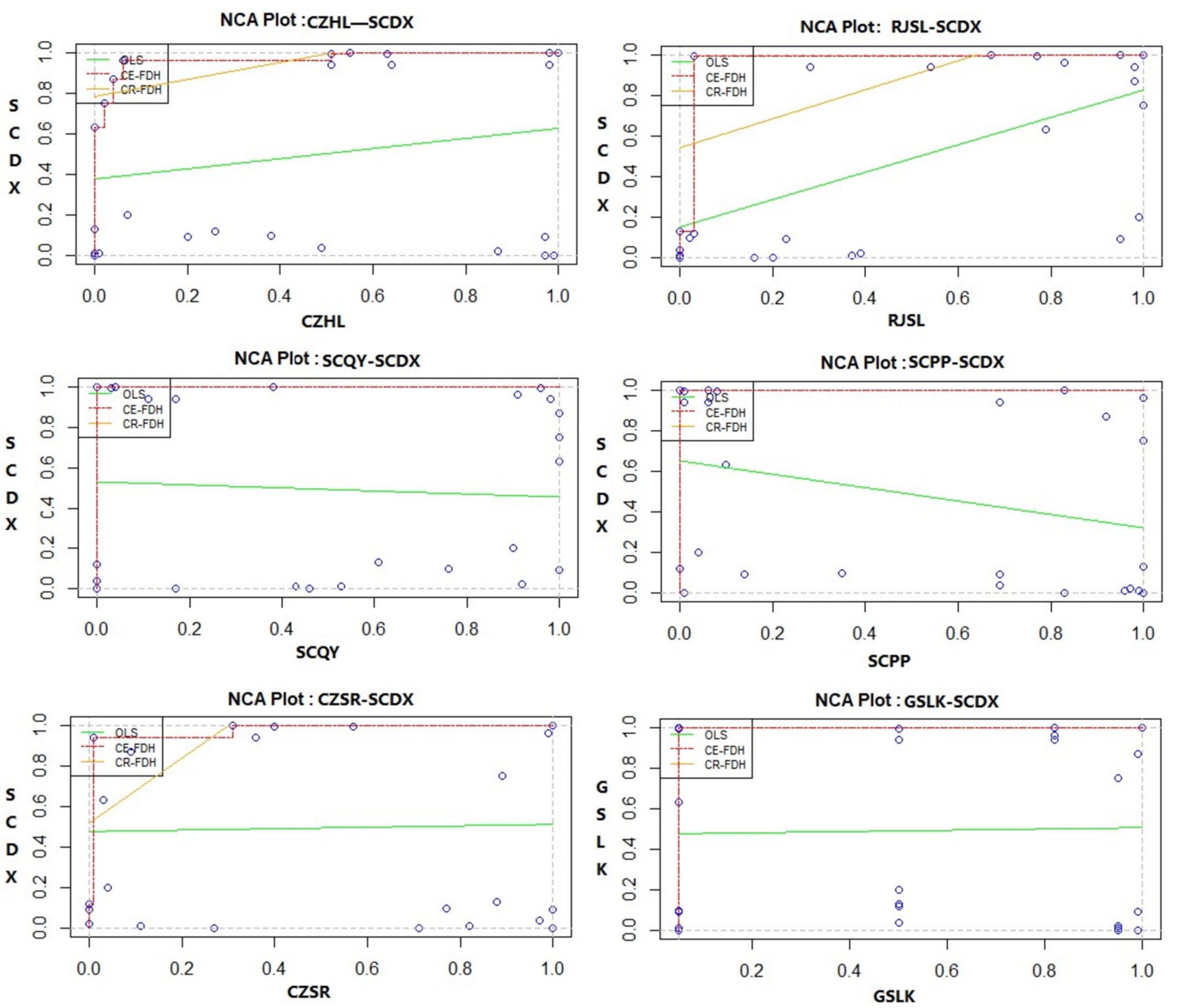

FIGURE 2
NCA scatter plot.

TABLE 3 **Results of necessary condition analysis by NCA.**

Causal conditions	Method	Precision	Upper limit	Radius	Effect size (d)	*p* value
CZHL	CR	92	0.056	1.00	0.056	0.010
	CE	100	0.033	1.00	0.033	0.011
RJLS	CR	89	0.148	1.00	0.148	0.002
	CE	100	0.033	1.00	0.033	0.021
SCQY	CR	100	0.00	1.00	0.000	1.000
	CE	100	0.00	1.00	0.000	1.000
SCPP	CR	100	0.00	1.00	0.000	1.000
	CE	100	0.00	1.00	0.000	1.000
CZSR	CR	85	0.073	1.00	0.073	0.018
	CE	100	0.027	1.00	0.027	0.033
GSLK	CR	100	0.00	0.95	0.000	1.000
	CE	100	0.00	0.95	0.000	1.000

solutions, parsimonious solutions, and intermediate solutions obtained are identical for the complex and intermediate solutions. In the “High (SCDX)” set analysis, six intermediate solutions and four parsimonious solutions are obtained, whereas in the “Non-High (~SCDX)” set analysis, four intermediate solutions and one parsimonious solution are obtained. The intermediate solutions and their corresponding explanatory cases are shown in Table 5.

In Table 5, the top part presents the analysis results of the “high level” set, and the bottom part presents the analysis results of the “nonhigh level” set. The verification analysis on the basis of the actual situation of the 26 high vegetable production counties in Henan Province generally aligns with the actual situation. The “high-level” counties mostly consist of traditional high vegetable production counties with large planting areas and, more importantly, early transformation, with relatively mature technology and market structures. The “nonhigh-level” counties mostly consist of emerging high-level large vegetable-producing counties that are shifting away from but are currently still considered to be major wheat-producing counties. While the absolute area of vegetable cultivation is relatively large, the relative area is small. Among the ten configuration constructs, no contradictory explanations are found for various causal conditions in different configurations, and their roles are consistent with their consistency values.

TABLE 4 Bottleneck level testing for different outcome conditions (%).

SCDX	CZHL	RJLS	SCQY	SCPP	CZSR	GSLK
0	NN	NN	NN	NN	NN	NN
10	NN	NN	NN	NN	NN	NN
20	NN	NN	NN	NN	NN	NN
30	NN	NN	NN	NN	NN	NN
40	NN	NN	NN	NN	NN	NN
50	NN	NN	NN	NN	NN	NN
60	NN	8.4	NN	NN	5.3	NN
70	NN	22.4	NN	NN	11.5	NN
80	3.6	36.4	NN	NN	17.7	NN
90	27.7	50.3	NN	NN	24.0	NN
100	51.8	64.3	NN	NN	30.2	NN

A common method for interpreting analysis results is to use intermediate solutions to determine the number of configurations leading to the outcome and the conditions included in these configurations. Then, the results of the parsimonious solutions are used to identify the core conditions that are more important for a given configuration (Fiss, 2011). The conditions appearing in the parsimonious solutions are called core conditions for a given configuration, indicating a strong causal relationship with the outcome. The remaining conditions that appear in the intermediate solutions but not in the parsimonious solutions are called peripheral conditions, indicating a weaker causal relationship with the outcome.

Combining the intermediate solutions and parsimonious solutions for analysis yields the final path configurations. In Table 6, ● or ◑ indicates the presence of a condition, whereas ⊗ or ⊙ indicates the absence of a condition. ● or ⊗ represents a core condition, whereas ◑ or ⊙ represents a peripheral condition (Xiong and Sun, 2023). A blank space means that the condition may or may not be present. The core conditions are those that appear in both the parsimonious and intermediate solutions, and the peripheral conditions are those that have been removed from the parsimonious solutions but appear in the intermediate solutions. RJLS was previously identified as a necessary condition in the NCA test, but it is not absent in any configuration constructed by fsQCA, meaning that the NCA identification results need not be considered further (Acquah, 2024).

In the S1 configuration, only two conditions are needed, namely, the urbanization rate and *per capita* social consumption retail sales. With a certain urbanization rate and a certain consumption level, a high-vegetable-production county can be supported. In the S2 configuration, three conditions are needed, namely, a certain urbanization rate, a certain consumption level, and local fiscal budget revenue. Local economic strength provides significant support for the planned development of vegetable production. The S3 configuration explains only the case of Nanle County, which, as a high-vegetable-production county, has relatively weak conditions in seven aspects. Despite being located far from major cities and having low local fiscal budget revenue, Nanle County has leveraged its local urbanization rate and geographical advantage to achieve large-scale vegetable production. Vegetable production in Nanle County also benefits from the surrounding special environment, i.e., neighboring Shandong Province. The higher levels of vegetable production technology in the surrounding areas have had some spillover effects, and the higher

TABLE 5 Configurations of intermediate and parsimonious solutions and their explanatory cases.

Configuration	Case (county/district)
1. CZHL*RJLS* ~ SCPP* ~ CZSR* ~ GSLK	Zhaoling (0.67, 1), Xinye (0.6, 0.99)
2. CZHL*RJLS* ~ SCQY*CZSR*GSLK	Huiji (0.82, 1), Zhongmu (0.62, 1)
3. CZHL* ~ RJLS* ~ SCQY* ~ SCPP* ~ CZSR*GSLK	Nanle (0.64, 0.94)
4. ~CZHL*RJLS*SCQY*SCPP*CZSR*GSLK	Luyi (0.89, 0.75), Fugou (0.82, 0.96)
5. CZHL*RJLS* ~ SCQY* ~ SCPP* ~ GSLK	Zhaoling (0.67, 1), Linying (0.55, 1)
6. CZHL*RJLS* ~ SCQY* ~ SCPP*CZSR	Huiji (1, 1), Linying (0.55, 1)
1. ~CZHL* ~ RJLS*SCQY*SCPP* ~ GSLK	Xiayi (0.69, 0.91), Xiping (0.53, 0.99)
2. CZHL* ~ RJLS* ~ SCQY*SCPP*CZSR	Tangyin (0.83, 1), Ye (0.54, 1)
3. ~CZHL* ~ RJLS* ~ SCQY*SCPP* ~ CZSR*GSLK	Huaxian (0.57, 0.99)
4. CZHL* ~ RJLS*SCQY*SCPP* ~ CZSR*GSLK	Weishi (0.61, 0.98)

TABLE 6 Configurations for achieving high−/nonhigh-level large vegetable-producing counties.

Causal condition	High-level large vegetable-producing county						Nonhigh-level large vegetable producing county			
	S1	S2	S3	S4	S5	S6	S1	S2	S3	S4
CZHL	●	●	●	⊙	●	●	⊙	◑	⊙	◑
RJLS	●	●	⊙	●	●	●	⊗	⊗	⊗	⊗
SCQY		⊗	◑	◑	⊗	⊗	◑	⊙	⊙	◑
SCPP	⊗		⊗	◑	O	⊗	●	●	●	●
CZSR	⊗	●	⊙	●		●		◑	⊙	⊙
GSLK	⊙	◑	◑	◑	⊙		⊙		◑	◑
Consistency	0.953	0.911	0.906	0.883	0.995	1.000	0.187	0.172	0.080	0.088
Original coverage	0.188	0.159	0.112	0.154	0.156	0.193	0.131	0.117	0.040	0.041
Unique coverage	0.087	0.035	0.071	0.129	0.000	0.014	0.911	0.958	0.972	0.967
Global consistency	0.911						0.956			
Overall coverage	0.569						0.411			

level of economic development in the area has promoted the development of vegetable production in Nanle County.

The S4 configuration explains the cases of two counties from Zhoukou Prefecture, namely, Luyi County and Fugou County. While the urbanization rates of these two counties are not high, the other conditions are relatively balanced, among which the local financial level is an important condition, indicating that the two county governments are very supportive of the development of vegetable production. In addition, the vegetable enterprise organization and brand building of the two counties also play important roles. The configurations of S5 and S6 are close, and the first two conditions are the core conditions, which are the same as those of S1 and S2. Linying County appears in these two configurations, and the development of its vegetable industry is also due mainly to market demand and the support of the local government.

In all the "high-level, large, vegetable-producing counties" configurations, the role of vegetable enterprises and vegetable brands seems to be minor, indicating that the development of vegetable production in Henan Province is still in the initial stage and that many vegetable cooperation organizations and processing enterprises either do not play any role or play a role in name only. The levels of green vegetable, organic vegetable and geographical indicator vegetable use and other market awareness levels are very low. There is not enough publicity of the topic, which indicates that consumers are not yet sensitive to the topic; such publicity is determined by the level of economic development.

In the "nonhigh-level, large, vegetable-producing county" configuration, the vegetable brand (SCPP) is the core condition of existence, and the local consumption level is the core condition of nonexistence. This shows that the restriction factor that leads to the relatively small scale of vegetable production is the low level of local consumption, and the vegetable brand does not play a corresponding role. These large vegetable-producing counties should further engage in further development, especially with regard to the local economy, engage in active resident consumption, and use the brand to open up external markets; furthermore, the government should create better basic conditions, and vegetable enterprise organizations should play a role in organizing and coordinating the export of vegetables to other regions.

7.3 Robustness test

Examining the robustness of the analysis results is a critical step in qualitative comparative analysis (QCA) research. Robustness tests in QCA encompass various methods, with the common approach being the reasonable adjustment of relevant parameters, such as calibration criteria, minimum case frequency, and consistency thresholds. The analysis is then repeated with the adjusted data, and the changes in configurations are compared to evaluate the reliability of the results (Leppänen et al., 2023). If parameter adjustments do not lead to substantial changes in the number, components, consistency, and coverage of the configurations, then the analysis results can be considered reliable (Greckhamer and Gur, 2021).

During data calibration, different membership and nonmembership calibration points, such as (0.95, 0.05), (0.8, 0.2), (0.75, 0.25), and (0.6, 0.4), are adjusted. Different calibration values lead only to variations in the number of explained cases without causing conflicts in the explanations. Among these, the calibration point (0.75, 0.25) produces configurations and explains cases that are relatively balanced and are thus used as anchors for analysis (Wagemann and Schneider, 2015).

During the analysis, the consistency decreases to 0.7, and the proportional reduction in inconsistency (PRI) increases to 0.8. The robustness test results for these two settings are presented in Table 7. The intermediate solution still consists of six configurations, with the addition of the cases of Huaiyang, Suiyang, and Xihua. Compared with Table 5, the corresponding configurations and case logic are consistent and without contradictions. Similarly, without changing the consistency threshold, adjusting the PRI threshold from 0.75 to 0.8 results in four intermediate solutions, which differ very little from the first four configurations outlined (refer to Table 5). The only change is the loss of one case (Zhongmu).

TABLE 7 Robustness test.

No.	Configuration	Case (county/district)
Configuration and interpretation case when consistency =0.7		
1	CZHL*RJLS* ~ SCQY* ~ SCPP* ~ GSLK	Zhaoling (0.67, 1+), Linying (0.55, 1)
2	RJLS*SCQY* ~ SCPP* ~ CZSR* ~ GSLK	Huaiyang (0.79, 0.63), Xinye (0.6, 0.99)
3	CZHL*RJLS* ~ SCQY* ~ SCPP*CZSR	Huiji (1, 1), Linying (0.55, 1)
4	CZHL*RJLS* ~ SCQY*SCPP*GSLK	Suiyang (0.69, 0.94), Zhongmou (0.62,1)
5	~CZHL*RJLS*SCQY*SCPP*GSLK	Luyi (0.95, 0.75), Xihua (0.92, 0.87), Fugou (0.82, 0.96)
6	CZHL* ~ RJLS* ~ SCQY* ~ SCPP* ~ CZSR*GSLK	Nanle (0.64, 0.94)
Configuration and interpretation case when PRI=0.8		
1	CZHL*RJLS* ~ SCPP* ~ CZSR* ~ GSLK	Zhaoling (0.67, 1), Xinye (0.6, 0.99)
2	CZHL*RJLS* ~ SCQY* ~ SCPP*CZSR	Huiji (1, 1), Linying (0.55, 1)
3	CZHL* ~ RJLS* ~ SCQY* ~ SCPP* ~ CZSR*GSLK	Nanle (0.64, 0.94)
4	~CZHL*RJLS*SCQY*SCPP*CZSR*GSLK	Luyi (0.89, 0.75), Fugou (0.82, 0.96)

8 Conclusion and implications

On the basis of the previous three-dimensional theoretical framework and configuration analysis, it is concluded that county-level large-scale vegetable production in Henan is driven mainly by the market demand side, followed by the public service side and relatively weak supply side. These findings indicate that the roles of vegetable growers, cooperatives, middlemen and public services, etc., might not have been fully mobilized yet. In other words, county-level large-scale vegetable production in Henan Province is still in its nascent stage, primarily supplying the local market with limited subjective innovation and market expansion capabilities. However, as rural revitalization progresses, the county territory will gather increasingly more of the rural population, and even the urban retired population may move to the countryside. Moreover, given China's push for modernization, rural resident income will increase significantly over time. As consumption conceptions change, the rural population will demand more vegetables. All these factors will help drive large-scale vegetable production development at the county level.

To increase the level of vegetable production in county-level suburban areas in Henan Province, three general policy directions must be addressed as follows.

First, a demand-side investigation of the potential of vegetable consumption and its influencing factors should be conducted. To achieve this goal, it is crucial to understand county residents' willingness to purchase and consume vegetables. As mentioned above, the county territory will attract an increasing rural population, and even the urban retired population may move to the countryside. Moreover, given China's push for modernization, rural residents' income will increase significantly over time, and consumption conceptions will change. All these factors will help to increase the demand for large-scale vegetable production in the county. Moreover, it is necessary to understand middlemen's willingness to trade more vegetables because middlemen are a connecting bridge between the supply side and the demand side and thus play a holistic role in the vegetable demand chain.

Second, there should be a push to conduct a public-service innovation for county-level large-scale vegetable production to improve its business environment. To do so, governments should provide comprehensive infrastructure and convenient transportation and logistics conditions to reduce production transaction costs. The market circulation system should be optimized, cold chain logistics should be developed, and production and sales connectivity should be enhanced. Moreover, fostering and attracting leading vegetable enterprises to build integrated vegetable sector chains are necessary for Henan Province to transform into a precooked vegetable production base.

Third, a supply-side survey should be conducted for growers to produce more vegetables; while a focus on the supply side is not a critical general policy direction, it does sometimes stimulate consumption. To achieve this goal, it is crucial to understand growers' willingness to produce more quality vegetables. For example, it is necessary to innovate vegetable varieties and plant consumers' preferred varieties. In addition, it is important to increase science and technology investment, improve vegetable productivity, reduce production costs, reduce chemical fertilizer and pesticide inputs, and guarantee vegetable quality. Moreover, understanding middlemen's willingness to trade more vegetables is useful because middlemen also play a logistic role in the vegetable supply chain.

Finally, this study has several limitations. The fsQCA approach used in this paper provides only a general policy direction (e.g., demand-side, supply-side, or public-side directions) for county-level large-scale vegetable production. However, for specific influencing factors, a concrete investigation is necessary. For example, which specific demand-side or public-side factors influence county-level large-scale vegetable production? Also, although the fsQCA approach does not require a large sample size, increasing the sample size in future related studies could improve the estimation efficiency.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: not applicable.

Author contributions

WW: Formal analysis, Data curation, Conceptualization, Writing – original draft. HT: Writing – review & editing, Methodology, Formal analysis, Conceptualization. HM: Writing – original draft, Supervision, Project administration, Funding acquisition, Writing – review & editing.

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Conflict of interest

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