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Spatial–temporal analysis of the comparative advantages of dairy farming: Taking 18 provinces or municipalities in China as an example

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ABSTRACT

High cost and low milk yield per dairy cow are current problems mainly faced by dairy farms in China. Thus, optimizing the regional layout and integrating the advantages to enhance the competitiveness of dairy farming in China is necessary. However, existing studies on comparative advantage analysis of dairy breeding have a relatively single perspective. Therefore, comprehensively identifying the advantage area of dairy farming is difficult. This study established a comprehensive evaluation model of the comparative advantages of dairy farming considering basic, technical, economic, and feed resource indexes using linear weighted and entropy weight methods. On this basis, the spatial–temporal analysis of the comprehensive evaluation on comparative advantages of dairy farming from 2013 to 2017 was performed using Geographic Information System(GIS). Finally, the advantage areas of dairy farming were identified. Results demonstrated that the highest average comprehensive evaluation value was 0.6017 in Inner Mongolia Autonomous Region, followed by 0.5355 in Ningxia Hui Autonomous Region and 0.1786 in Anhui Province. Furthermore, the advantage areas of dairy farming were identified including Inner Mongolia Autonomous Region, Beijing Municipality, Heilongjiang Province, Shanghai Municipality, Xinjiang Uygur Autonomous Region, Tianjin Municipality, Liaoning Province, Shanxi Province and Ningxia Hui Autonomous These findings provide references for the spatial layout of dairy farming, spatial allocation of production resources, and sustainable development of animal husbandry.

1. Introduction

With the rapid development in recent years, the dairy farming of China has become the world's third-largest milk producer (Li, 2015). This industry plays a crucial role in increasing the income of farmers, optimizing the economic structure in rural areas, and improving the dietary structure of residents in China (Yang et al., 2013; Li, 2019). However, this industry is currently facing several problems, such as high cost and low milk yield per dairy cow (Yu et al., 2018; Zhao et al., 2018). Therefore, enhancing the competitiveness of China's dairy industry by optimizing the regional layout and integrating advantageous factors is of great significance (Yu and Li, 2012). The advantage areas in China should be determined by analyzing the regional comparative advantage of dairy farming. The determination of such areas is also the strategic layout of the national development and the decision-making policy and strategic guidance of the local development direction of the dairy industry in the future (Li, 2015).

Many researchers have conducted comparative advantage analysis of dairy farming using different methods, such as domestic resource cost method (Murphy, 1989), revealed comparative advantage indicators (Drescher and Maurer,1999), probability advantage analysis (Yu and Li, 2012), data envelopment analysis (DEA) (Uzmay et al., 2009; Gaspar et al., 2009; Latruffe et al., 2012; Kelly et al., 2012; Shortall and Barnes, 2013; Siafakas et al., 2019), life cycle analysis (Soteriades et al., 2016), policy analysis matrix (Posadas-Domínguez et al., 2018), and resource endowment index (Li, 2019). Murphy (1989) evaluated the comparative advantage of dairy farming in countries within the European community using the domestic resource cost method. Drescher and Maurer (1999) confirmed the competitive position of the German dairy industry using revealed comparative advantage indicators at the *meso*-economic level. Through probability advantage analysis, Yu and Li (2012) compared the regional advantages of dairy farming in China and determined Tianjin,

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Hebei, Shandong, Henan, and Shanxi as the dominant farming areas of the country. Posadas-Domínguez et al. (2018) assessed the economic contribution of comparative advantages to private profitability and competitiveness of small-scale dairy systems through policy analysis matrix with sensitivity and poverty line analyses. Siafakas et al. (2019) evaluated the efficiency of dairy cow farms in Greece through DEA.

The previous studies mainly focused on the comparative advantage analysis of dairy farming in a single perspective. Thus far, studies on the comprehensive evaluation of comparative advantages of dairy farming are limited. However, the advantages of dairy farming are affected by many factors, such as feed resources, market economics, and technology (Yu and Li, 2012; El Benni and Finger, 2013; Li, 2015; Sirajuddin et al., 2017; Fathollahi et al., 2018; Siafakas et al., 2019). Thus, the results of single-perspective research might lead to a deviation in the actual outcomes. In this study, taking basic, technical, economic, and feed resource indexes into consideration, we established a comprehensive evaluation index system of the comparative advantages of dairy farming. Linear weighted and entropy weight methods were then used to construct the comprehensive evaluation model of the comparative advantages of dairy farming. Subsequently, the GIS spatial and spatial–temporal analyses of the comprehensive evaluation on comparative advantages of dairy farming from 2013 to 2017 were combined to identify the area with high comparative advantage value of dairy farming.

The objectives of this research are as follows: (i) to establish a comprehensive evaluation index system for the comparative advantages of dairy farming, (ii) to develop a comprehensive evaluation model of these advantages, and (iii) to perform spatial–temporal analysis of the comparative advantages of dairy farming and identify advantage areas.

2. Data and methods

2.1. Data collection and distribution

The milk yield, number of dairy cows, planting area of different crops (including maize, soybean, and green fodder), and crop yield from 2013 to 2017 were collected from the China Rural Statistical Yearbook, China Animal Husbandry and Veterinary Yearbook, and China Agriculture Yearbook. The per capita consumption expenditures of households and population data in the same period were obtained from the China Statistical Yearbook. The input and output data of dairy farming (including the output of the main products), feed costs (including concentrated feed and green and coarse fodder), water cost, fuel and power costs, medical and epidemic prevention costs, number of employees per unit, and indirect production costs from 2013 to 2017 were obtained from the Compilation Data of Cost and Profit of Agricultural Products in China. The graphs presented in this paper were generated using ArcGIS10.2 software and Excel 2013. DEA was used to analyze the comprehensive efficiency in dairy farming through DEAP version 2.1. The entropy weight method was utilized to calculate the weights of the indexes.

2.2. Advantage indexes

Scale advantage index is the comparison between the proportion and the average proportion of the planting area of a certain crop in a certain area in the entire country. This index can be calculated as follows (Tan and Gao, 2018; Ding et al., 2018; Yan et al., 2020):

$$S_{ab} = \frac{F_{ab}/F_a}{F_b/F_q}. \quad (1)$$

② Efficiency advantage index is the ratio between the proportion of yield of a certain crop per unit area in a certain area and that in the entire country. The efficiency advantage index can be calculated as follows (Tan and Gao, 2018; Ding et al., 2018; Yan et al., 2020):

$$E_{ab} = \frac{W_{ab}/W_a}{W_b/W_t}. \quad (2)$$

③ Aggregated advantage index combines the scale advantage index and efficiency advantage index to reflect the advantage degree of certain crop production in a area comprehensively. The formula is as shown below (Tan and Gao, 2018; Ding et al., 2018; Yan et al., 2020):

$$A_{ab} = \sqrt{S_{ab} \times E_{ab}}. \quad (3)$$

where S_{ab}, E_{ab}, A_{ab} denote the scale advantage index, efficiency advantage index and aggregated advantage index respectively; F_{ab} denotes crop planting area b in area a; F_a denotes all crop planting area in province or municipality a; F_b denotes crop planting area b in China; F_q denotes all crop planting area in China; W_{ab} denotes crop yield b per unit area in province or municipality a; W_a denotes average all crop yield per unit area in province or municipality a; W_b denotes crop yield b per unit area in China; W_q denotes average all crop yield per unit area in China.

2.3. DEA

DEA, which was initially proposed by Charnes et al. (1978), is a non-parametric method of evaluating the relative efficiency of decision-making units (DMUs). The DMUs are evaluated in accordance with the inputs and outputs using linear programming techniques (Charnes et al., 1978). This approach is known as the input-oriented DEA model under variable returns to scale (Banker et al., 1984; Charles et al., 2019). DEA can be calculated as follows (Banker et al., 1984; Jin et al., 2018; Charles et al., 2019):

$$\begin{cases} \min\theta \\ s.t. \sum_{j=1}^{n} \lambda_j x_j + s^- = \theta x_0 \\ \sum_{j=1}^{n} \lambda_j y_j - s^+ = y_0 \\ \lambda_j \geqslant 0, j = 1, 2, \cdots, \cdots n \\ s^+ \geqslant 0 \\ s^- \geqslant 0 \end{cases} \quad (4)$$

where θ denotes the comprehensive efficiency, and the larger the value is, the higher the comprehensive efficiency is; $\boldsymbol{x_0}$ denotes the input variable of evaluation decision unit; $\boldsymbol{y_0}$ denotes output variables of evaluation decision unit; $\boldsymbol{x_j}$ denotes the input of the province j; $\boldsymbol{y_j}$ denotes the output of the province j; λ_j denotes combination coefficient of each unit; s^+ denotes relaxation variable; s^- denotes residual variable.

2.4. Entropy weight method

The entropy weight method, based on Shannon entropy, was proposed by Shannon and Weaver (1947). This method can be used to determine the weights of indexes according to the entropy by measuring the information included in the data of an evaluation index system (Wang et al., 2015). The procedure for the entropy weight method is presented as follows.

Step 1: Standardization of indexes (Delgado and Romero, 2016; Yan et al., 2020).

$$H_n^i = \frac{D_n^i - D_{min(n)}}{D_{max(n)} - D_{min(n)}}, \quad (5)$$

$$H_n^i = \frac{D_{max(n)} - D_n^i}{D_{max(n)} - D_{min(n)}}. \quad (6)$$

Step 2: Calculation of the entropy (Wang et al., 2015; Delgado and Romero, 2016).

$$G_i = -ln(m)^{-1}\sum_{i=1}^{n} R_{ij} ln R_{ij}, \tag{7}$$

$$R_{ij} = \frac{H_{ij}}{\sum_{j=1}^{n} H_{ij}}. \tag{8}$$

Step 3: Calculation of the entropy weight of the index (Wang et al., 2015; Delgado and Romero, 2016).

$$W_i = \frac{1 - G_i}{\sum_{i=1}^{n}(1 - G_i)}. \tag{9}$$

where $D_{max(n)}$ denotes maximum value of index i; $D_{min(n)}$ denotes minimum value of index i; D_n^i denotes index i; H_n^i denotes standardization result of indexes i; G_i denotes the entropy value of index; W_i denotes the entropy weight of index; n denotes number of index i; m denotes number of samples.

2.5. Comprehensive evaluation model of the comparative advantages of dairy farming

A comprehensive evaluation index system of the comparative advantages of dairy farming was first established considering the following indexes: price of soybean meal, per capita dairy cows, comprehensive efficiency of dairy farming, aggregated advantage indexes of corn and soybean, scale advantage index of green fodder, per capita consumption expenditure of households, and average milk yield per dairy cow (Murphy, 1989; Aubron et al., 2009; Yu and Li, 2012; El Benni, and Finger, 2013; Li, 2015; Janković et al., 2016; Sirajuddin et al., 2017; Fathollahi et al., 2018; Yu et al., 2018; Siafakas et al., 2019; Yan et al., 2020). Subsequently, the indexes were standardized through the range method, and their corresponding weights were determined using the entropy weight method. Finally, with reference to the method in the literature (Yan et al., 2020), a comprehensive evaluation model of the comparative advantages of dairy farming was established based on the linear weighted method. The comprehensive evaluation model can be expressed as follows:

$$V = P_i \times f_i \tag{10}$$

where V denotes the comprehensive evaluation value of the comparative advantages of dairy farming; P_i denotes the index value; and f_i denotes the index weight.

3. Results

3.1. Number of dairy cows in 18 provinces or municipalities in China during 2013–2017

The number of dairy cows in 18 provinces or municipalities in China from 2013 to 2017 was obtained from China Rural Statistical Yearbook and China Agriculture Yearbook. The results are presented in Fig. 1. As shown in Fig. 1, there is wide variation in the number of dairy cows among 18 provinces or municipalities in China from 2013 to 2017.

From 2013 to 2017, the provinces or municipalities with a large number of dairy cows were located in Inner Mongolia Autonomous Region (14.72%), Xinjiang Uygur Autonomous Region (13.94%), Heilongjiang Province (12.70%), and Henan province (6.39%). By contrast, Chongqing Municipality, Fujian Province, and Shanghai Municipality had relatively small numbers of dairy cows, accounting for 0.13%, 0.35%, and 0.42% of the total number of dairy cows from 2013 to 2017, respectively. The total number of dairy cows in 18 provinces or municipalities was 9,622,000, accounting for 69.20% of the total number of dairy cows from 2013 to 2017 in China. Inner Mongolia Autonomous Region has the largest share of dairy cows (2,046,600), followed by Xinjiang Uygur Autonomous Region (1,937,800) and Chongqing Municipality (17,800).

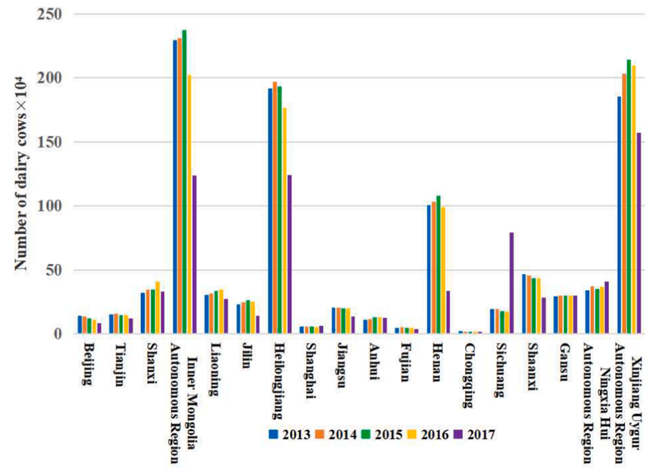

Fig. 1. Number of dairy cows in 18 provinces or municipalities in China during 2013–2017.

The number of dairy cows in Beijing and Chongqing Municipalities continuously decreased from 2013 to 2017. Similarly, those in Inner Mongolia Autonomous Region, Heilongjiang Province, Henan Province, and Xinjiang Uygur Autonomous Region dramatically decreased in 2017. By contrast, the number of dairy cows in Shanghai Municipality, Ningxia Hui Autonomous Region, and Sichuan Province increased in 2017. In particular, the number of dairy cows in Sichuan Province dramatically increased from 176,000 in 2016 to 790,000 in 2017.

3.2. Spatial distribution result of comprehensive evaluation indexes of the comparative advantages of dairy farming in 18 provinces or municipalities in China

The average values of the prices of soybean meal, per capita consumption expenditure of households, per capita dairy cows, and milk yield per dairy cow in 2013–2017 were obtained from China Rural Statistical Yearbook and China Agriculture Yearbook. The average values of the aggregated advantage index of corn and soybean and scale advantage index of green fodder in the same period were calculated using Equations (1)–(3). The average DEA of dairy farming from 2013 to 2017 was calculated using Equation (4) considering the outputs of the main products, feed costs, number of employees per unit, and indirect production costs. Subsequently, the spatial distribution result of comprehensive evaluation indexes of the comparative advantages of dairy farming was obtained using GIS spatial analysis. These results were graded in accordance with the threshold or the Jenks natural breaks method (Fig. 2).

Fig. 2a indicates that Xinjiang Uygur Autonomous Region, Ningxia Hui Autonomous Region, Fujian Province, Sichuan Province, Beijing Municipality, Gansu Province, Inner Mongolia Autonomous Region, and Chongqing Municipality possess comparative advantages in terms of green fodder production. The highest comparative advantage was obtained by Ningxia Hui Autonomous Region (5.4210), followed by Inner Mongolia Autonomous Region (3.0257). Henan Province had the lowest comparative advantage (0.0239). Except for Fujian Province, Shanghai Municipality, and Jiangsu Province, the 15 other provinces or municipalities demonstrated comparative advantages in terms of corn production (Fig. 2b). The highest and lowest values were obtained by Jilin Province (2.6926) and Shanghai Municipality (0.5417). Fig. 2c shows that Shanxi Province, Anhui Province, Heilongjiang Province, Inner Mongolia Autonomous Region, and Jilin Province have comparative advantages in terms of soybean production. The highest value obtained by Heilongjiang Province was 2.9085, followed by Inner Mongolia Autonomous Region with 1.6437 and Shanghai Municipality with 0.2562. Liaoning Province, Beijing Municipality, Tianjin Municipality,

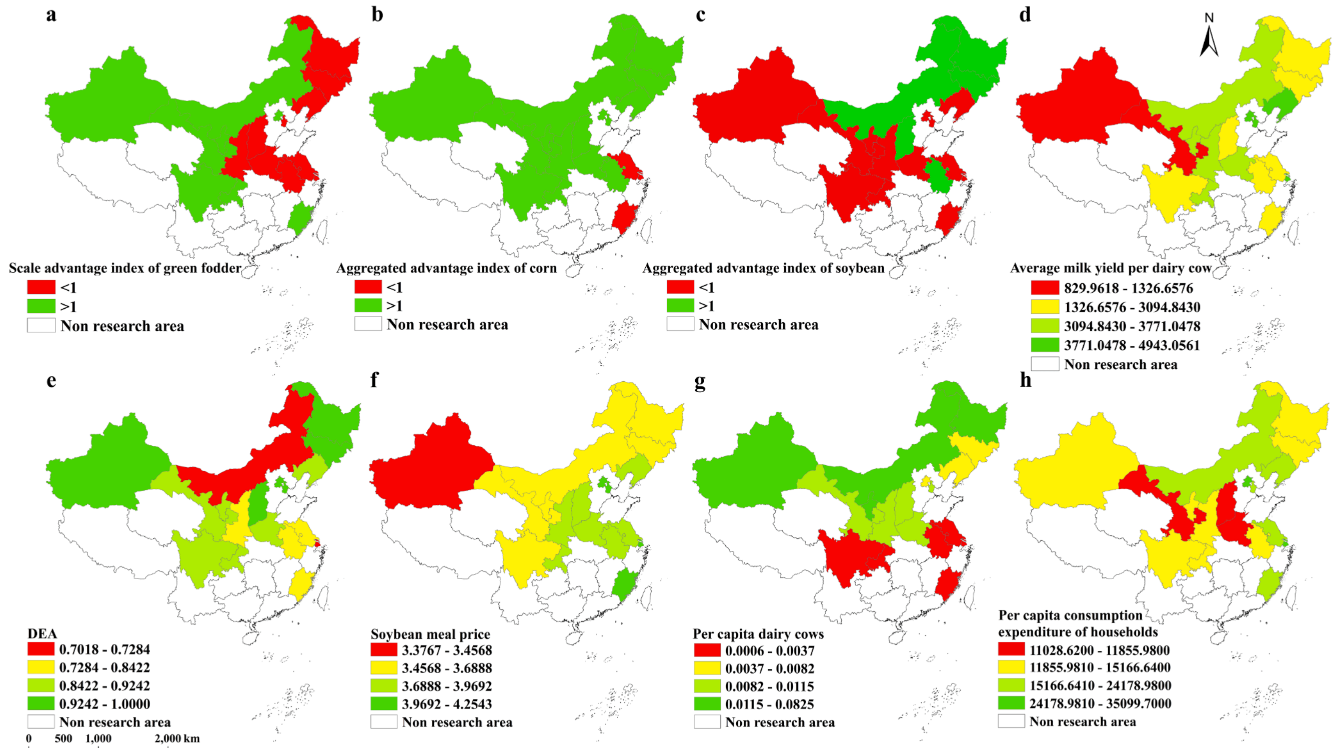

Fig. 2. Spatial distribution result of comprehensive evaluation index on comparative advantages of dairy farming in 18 provinces or municipalities in China.

and Shanghai Municipality exhibited comparative advantages of average milk yield per dairy cow (Fig. 2d). Shanghai municipality obtained the highest comparative advantage, whereas Xinjiang Uygur Autonomous Region obtained the lowest. Fig. 2e indicates that Heilongjiang Province, Jilin Province, Beijing Municipality, Tianjin Municipality, Shanxi Province, and Xinjiang Uygur Autonomous Region had high DEA values of dairy farming, while Inner Mongolia Autonomous Region and Shanghai Municipality had low DEA values. Heilongjiang Province, Tianjin Municipality, and Shanxi Province obtained the highest DEA value (1.0000), followed by Xinjiang Uygur Autonomous Region (0.9962). The lowest DEA value of 0.7018 was observed in Inner Mongolia Autonomous Region.

Fig. 2f demonstrates that Beijing Municipality, Tianjin Municipality, Shanghai Municipality, and Fujian province had comparative advantages considering soybean meal price. The highest soybean meal price of 4.2543 *yuan* was observed in Xinjiang Uygur Autonomous Region, followed by 3.9692 *yuan* in Sichuan Province. The lowest price soybean meal price of 3.3767 *yuan* was found in Tianjin Municipality. Fig. 2g shows that Heilongjiang Province, Inner Mongolia Autonomous Region, Ningxia Hui Autonomous Region, and Xinjiang Uygur Autonomous Region had comparative advantages considering per capita dairy cows. The highest per capita dairy cows of 0.0825 was observed in Xinjiang Uygur Autonomous Region, followed by 0.0815 in Inner Mongolia Autonomous Region. The lowest per capita dairy cows of 0.006 was found in Chongqing Municipality.

Fig. 2h demonstrates that Shanghai and Beijing Municipalities had high per capita consumption expenditure of households. The highest value of 35099.70 *yuan* was observed in Beijing Municipality, followed by 33384.46 *yuan* in Shanghai Municipality. The lowest per capita consumption expenditure of households was 11028.62 *yuan* in Gansu province.

3.3. Spatial–temporal analysis result of the comprehensive evaluation of comparative advantages of dairy farming during 2013–2017

The spatial–temporal analysis result of the comparative advantages of dairy farming from 2013 to 2017 was determined using Equations (5)–(10) and GIS spatial analysis. The weight of the indexes is listed in Table 1.

The spatial–temporal analysis result was graded as high advantage, relative high advantage, medium advantage, low advantage, and no advantage according to the Jenks natural breaks method (Fig. 3 and Table 2).

Fig. 3 demonstrates the differences in the spatial–temporal analysis results of the comparative advantages of dairy farming in 18 provinces or municipalities from 2013 to 2017. Ningxia Hui Autonomous Region and Inner Mongolia Autonomous Region had consistently high dairy farming advantages. In addition, the average comprehensive evaluation of the comparative advantages of dairy farming from 2013 to 2017 was conducted (Fig. 3 and Table 2). Considering the average comprehensive evaluation value, Fig. 3 shows that Heilongjiang Province, Ningxia Hui Autonomous Region, Xinjiang Uygur Autonomous Region, and Inner Mongolia Autonomous Region had high comparative advantages of dairy farming, while Tianjin Municipality, Beijing Municipality, and

Table 1
Weights of the comprehensive evaluation indexes of comparative advantages of dairy farming during 2013–2017.

Indexes	2013	2014	2015	2016	2017
Soybean meal price	0.0311	0.0375	0.0586	0.0350	0.0487
Per capita dairy cows	0.3151	0.3149	0.2735	0.2775	0.2450
Comprehensive efficiency of dairy farming	0.0587	0.0539	0.0514	0.0908	0.0471
Aggregated advantage index of corn	0.0769	0.0799	0.0984	0.0709	0.0654
Aggregated advantage index of soybean	0.0685	0.0748	0.1274	0.1168	0.1212
Scale advantage index of green fodder	0.2215	0.2075	0.1787	0.1712	0.2346
Per capita consumption expenditure of households	0.1798	0.1839	0.1693	0.1934	0.1784
Average milk yield per dairy cow	0.0483	0.0476	0.0427	0.0443	0.0596

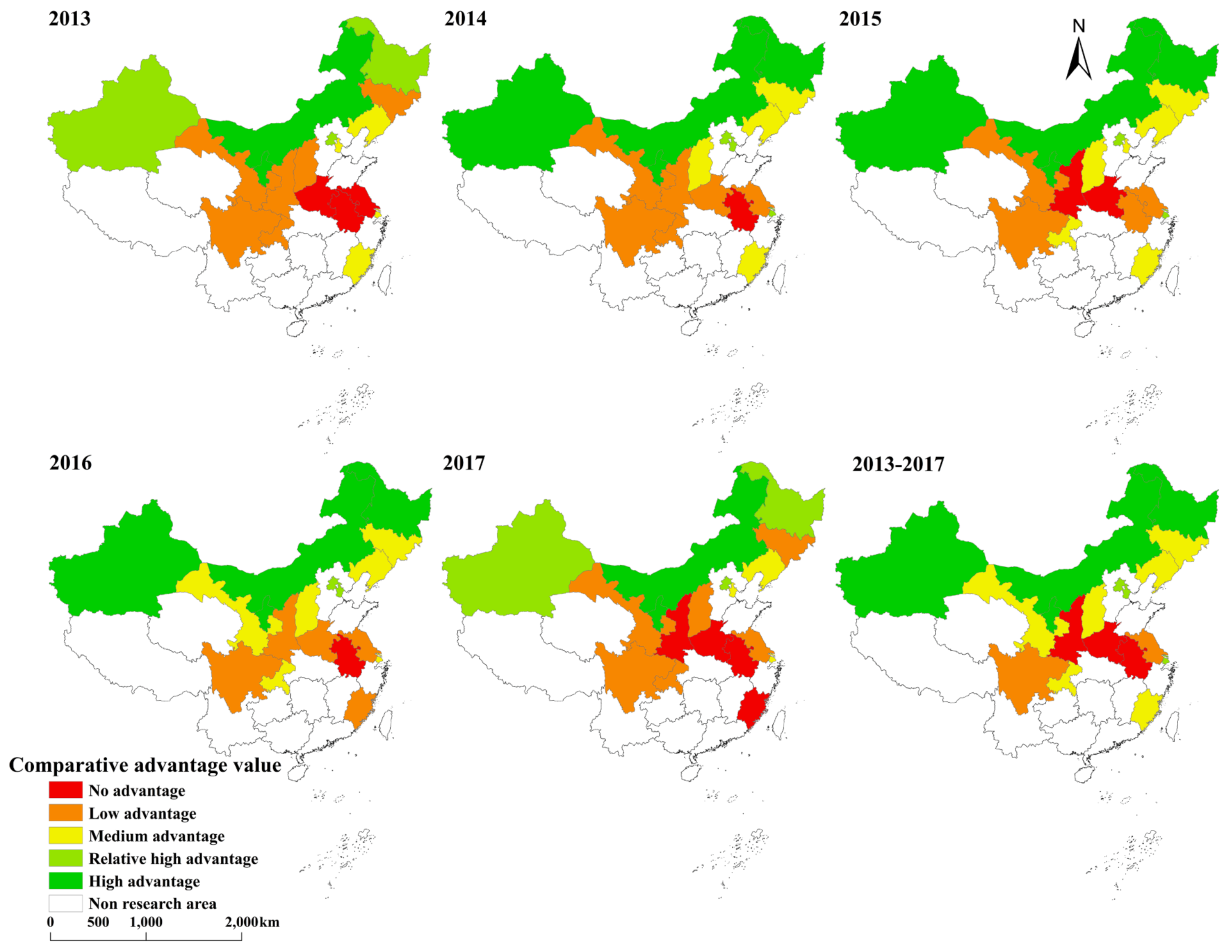

Fig. 3. Spatial-temporal analysis result of comprehensive evaluation on comparative advantages of dairy farming during 2013–2017.

Table 2
Statistic result of comprehensive evaluation on comparative advantages of dairy farming in China during 2013–2017.

Provinces or municipalities	2013	2014	2015	2016	2017	Average
Beijing	0.4074	0.4014	0.3686	0.4304	0.4037	0.4023
Tianjin	0.3120	0.3196	0.2840	0.3558	0.3143	0.3171
Shanxi	0.2415	0.2460	0.2446	0.2743	0.2402	0.2493
Inner Mongolia Autonomous Region	0.6628	0.6228	0.6208	0.5742	0.5277	0.6017
Liaoning	0.2683	0.2705	0.2407	0.3018	0.2663	0.2695
Jilin	0.2428	0.2500	0.2404	0.2737	0.2195	0.2453
Heilongjiang	0.4533	0.4534	0.4891	0.4865	0.4206	0.4606
Shanghai	0.3238	0.3173	0.3315	0.3057	0.3181	0.3193
Jiangsu	0.1927	0.2183	0.2271	0.1984	0.2115	0.2096
Anhui	0.1641	0.1690	0.2222	0.1650	0.1726	0.1786
Fujian	0.2733	0.2732	0.2485	0.2115	0.1738	0.2361
Henan	0.1915	0.1945	0.1959	0.1904	0.1937	0.1932
Chongqing	0.2354	0.2088	0.2493	0.2611	0.2351	0.2379
Sichuan	0.2253	0.2195	0.2199	0.2138	0.2089	0.2175
Shaanxi	0.2120	0.2011	0.1790	0.1996	0.1915	0.1966
Gansu	0.2486	0.2223	0.2252	0.2657	0.2067	0.2337
Ningxia Hui Autonomous Region	0.5471	0.5619	0.4967	0.4918	0.5802	0.5355
Xinjiang Uygur Autonomous Region	0.4657	0.4833	0.4724	0.4826	0.4172	0.4642

Shanghai Municipality had relatively high comparative advantages. Jilin, Gansu, Shanxi, Chongqing Municipality and Fujian Provinces had relative medium dairy farming advantages, while Jiangsu Province and Sichuan Province only had low advantages. As previously mentioned, Anhui province, Shaanxi Province and Henan province exhibited no dairy farming advantage.

Table 2 shows that the highest average comprehensive evaluation value of 0.6017 was obtained by Inner Mongolia Autonomous Region, followed by 0.5355 in Ningxia Hui Autonomous Region. The lowest average comprehensive evaluation value of 0.1786 was found in Anhui Province (Table 2).

Overall, these results suggest that Ningxia Hui Autonomous Region, Beijing Municipality, Heilongjiang Province, Shanghai Municipality, Xinjiang Uygur Autonomous Region, Tianjin Municipality, Liaoning Province, Shanxi Province and Inner Mongolia Autonomous Region could be identified as the advantage areas of dairy farming, as shown in Fig. 4.

4. Discussion and conclusions

A comprehensive evaluation index system and model of the comparative advantages of dairy farming were established in this study. Moreover, the spatial–temporal comprehensive evaluation of comparative advantages was conducted. The following nine advantage areas of dairy farming were identified: Inner Mongolia Autonomous Region, Beijing Municipality, Heilongjiang Province, Shanghai Municipality, Xinjiang Uygur Autonomous Region, Tianjin Municipality, Liaoning Province, Shanxi Province and Ningxia Hui Autonomous Region.

As previously stated, one major problem of dairy farming in China is

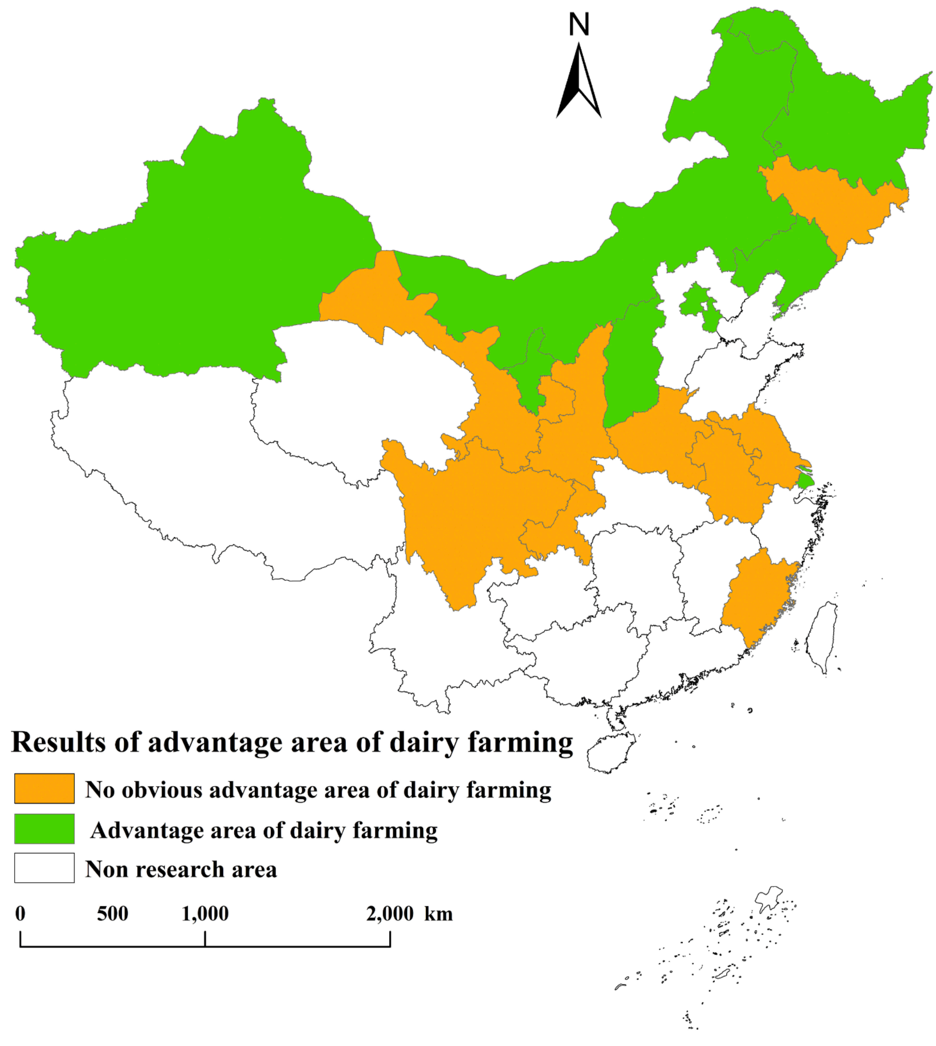

Fig. 4. Results of advantage area of dairy farming in 18 provinces or municipalities in China.

the low milk yield per dairy cow (Yu et al., 2018; Zhao et al., 2018). The results suggested that the milk yield per dairy cows in 18 provinces or municipalities was generally low, particularly in Xinjiang Uygur Autonomous Region. This area had the second largest number of dairy cows during 2013–2017, while its average annual milk yield during the period was only 829.96 kg per dairy cow. The highest average annual milk yield per dairy cow of 4943.05 kg was observed in Shanghai Municipality. However, the average annual milk yield per dairy cow in the United States, Israel, and Korea exceeded 10,000 kg per dairy cow (Guo et al., 2017). Some of the effective methods to increase the milk yield include optimizing dairy cow variety, improving dairy farming technology, and increasing the scale proportion of dairy farming (Yu et al., 2018). Another major problem is the high cost (Yu et al., 2018; Zhao et al., 2018). For example, the forage prices for corn, soybean meal, and alfalfa were considerably higher than those in developed countries and remained high for a long period (Yu et al., 2018; Liu et al., 2018). The results also indicated that the prices of soybean meal and corn were generally high during 2013–2017. The lowest corn price was 1.9662 yuan/kg in Heilongjiang Province, while the average corn price set by farms in the United States was only $ 0.124/kg (Liu et al., 2018).

This work established the comprehensive evaluation index system on comparative advantages of dairy farming considering the indexes, such as per capita dairy cows, soybean meal price, comprehensive efficiency of dairy farming, and aggregated advantage index of corn. The comparative advantage analysis of dairy farming in China also have been conducted by Yu and Li (2012) and Li (2019). Moreover, the comparative advantage analysis of dairy farming is also be carried out in the international context (Uzmay et al., 2009; Gaspar et al., 2009; Moreira and Bravo-Ureta, 2010; Latruffe et al., 2012; Kelly et al., 2012; Shortall and Barnes, 2013; Soteriades et al., 2016; Posadas-Domínguez et al., 2018; Siafakas et al., 2019; Sefeedpari et al., 2020). For example, Moreira and Bravo-Ureta (2010) compared technical efficiency and meta-technology ratios for dairy farms in Argentina, Chile and Uruguay by using the meta-frontier method. Posadas-Domínguez et al. (2018) assessed comparative advantages in the profitability and competitiveness of the small-scale dairy system of Tulancingo Valley, Mexico by combing Policy Analysis Matrix with a sensitivity and poverty line analysis. Using window data envelopment analysis, Sefeedpari et al. (2020) assessed technical efficiency of dairy farming based data from 25 provinces during 1994–2016 and identified the efficiency of 25 provinces in Iran. Compared with the studies from a relatively single perspective, comprehensive indexes were considered in this paper and results were close to reality. For example, the DEA was commonly used to gain comparative advantages of dairy farming (Uzmay et al., 2009; Latruffe et al., 2012; Kelly et al., 2012; Shortall and Barnes, 2013; Siafakas et al., 2019). The DEA can also be used to determine the comprehensive efficiency of dairy farming in this paper as shown in Fig. 2e. This figure demonstrates that Inner Mongolia Autonomous Region and Shanghai Municipality had low advantages in dairy farming, especially the Inner Mongolia Autonomous Region, which had the lowest DEA result in dairy farming. However, Inner Mongolia Autonomous Region and Shanghai Municipality had advantage areas of dairy farming according to comprehensive evaluation index system on comparative advantages of dairy farming. Previous studies also demonstrated that the result obtained by comprehensive indexes was more scientific than that obtained by single or multiple indexes (Yan et al., 2020).

Moreover, the areas with and without advantages in dairy farming were identified on the basis of the average advantage result of dairy farming from 2013 to 2017 (Fig. 4). These results could be applied to optimize the regional layout of dairy farming in China. On this basis, the transfer of dairy farming in areas with low or no advantage, such as Anhui Province, Chongqing Municipality, and Jiangsu Province, to Inner Mongolia Autonomous Region, Heilongjiang Province, and Xinjiang Uygur Autonomous Region, respectively, was suggested. Furthermore, Fig. 5 shows that the advantage areas of dairy farming identified by the proposed method were compared with those of the layout plan of the national advantage area of dairy farming in 2008–2015. The figure also demonstrates that the advantage areas in this study all belonged to the layout plan of the national advantage area of dairy farming in the aforementioned period. Thus, the obtained results are scientific and reasonable.

The results of the advantage area of dairy farming might affect the adjustment of regional agricultural structure such as planting structure and animal husbandry structure. This, in turn, reduces the production cost of dairy products and improves the economic benefits of agriculture. For example, the results might affect the spatial layout planning of corn planting because corn was one of the main forage resources in dairy farming (Fathollahi et al., 2018). In turn, the corn planting could supply rich feed to dairy farming. The results were also related to environmental pollution problem caused by dairy cow excreta. There are two possible situations that might cause environmental pollution. One is when dairy farming in areas with high advantage was expanded. Another is when dairy farming in areas with low or no advantage was transferred to dairy farming in areas with high advantage. The combination of planting and breeding was a widely adopted method to reduce environmental pollution risk caused by livestock farming (Lemaire et al., 2014; Duan et al., 2019; Li, 2019). Therefore, we should pay attention to the combination of planting and breeding and ensure that dairy cow excreta is properly disposed of.

In addition, the dairy farming was an important source of greenhouse-gas emissions and contributed about 4.35% of the total worldwide greenhouse-gas emissions (Gerber et al., 2013; Mostert et al., 2018). At present, the greenhouse-gas emissions reduction in livestock farming has become a hot topic of global concern (Ma and Zhao, 2012; York et al., 2018). The number of dairy cows and the results of the

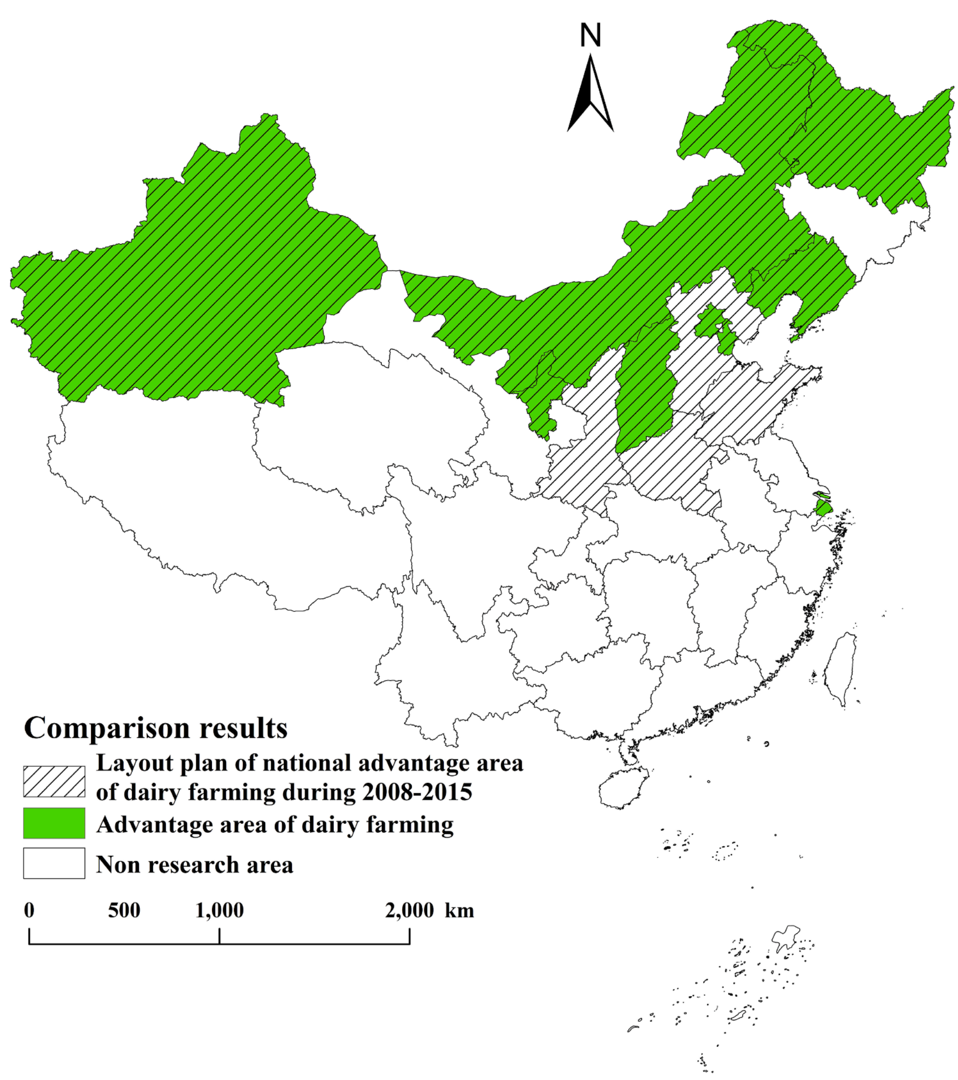

Fig. 5. The comparison results between the advantage areas of dairy farming in this paper and the layout plan of national advantage areas of dairy farming in 2008–2015.

advantage area of dairy farming in this paper can be used as a reference for greenhouse-gas emissions reduction in animal husbandry.

The current situation of China's dairy industry revealed that the trade of dairy products had been in deficit for a long time and the competitiveness of domestic dairy products was weak, especially from the melamine incident in 2008 (Qian et al., 2011; Zhao et al., 2018; Ding et al., 2019). The government had recently proposed to reinvigorate China's dairy industry. comprehensively through the No.1 Document in 2017 and expand and strengthen the industry through the No.1 Document in 2018 (Liu et al., 2018). Therefore, the results presented in this paper are crucial to optimize the regional layout of dairy farming and the allocation of resources and enhance the competitiveness of China's dairy industry. The results could also provide scientific guidance for developing the dairy industry in different provinces or municipalities of China in the future.

Furthermore, the results expanded the application scope of the comparative advantage theory. The results also indicated the reliability and usefulness of the entropy weight method, data envelopment analysis and GIS, which can provide a reference for other research. In addition, the results were conducive to optimize the layout of the global dairy industry, maintain the international trade balance of dairy products, and promote the sustainable development of global dairy farming.

Based on the results in this paper, we proposes some policy recommendations. First, the policymakers can make policy to optimize the layout of dairy farming according to unique spatial pattern in China. For example, a policy can be made to move dairy farming in the non-advantage area to the advantage area. Second, we recommend policymakers make policy to encourage the expansion of forage resources production for dairy farming such as corn planting, soybean planting and green fodder planting according to spatial distribution result of comprehensive evaluation index on comparative advantages of dairy farming. Third, we suggest policymakers make policy to improve dairy cow breeds by importing high yield breeding cattle, embryonic transplantation, etc. especially in Xinjiang Uygur Autonomous Region and Gansu Province because of very low milk yield per dairy cow. Finally, we recommend policymakers formulate preferential policies or facilitation measures such as capital subsidy and tax incentives.

The present study also has limitations. First, only the spatial–temporal analysis results of comparative advantages of dairy farming in 18 provinces or municipalities were presented due to lack of input and output data of dairy farming in other provinces or municipalities. Second, the indexes that might affect the aforementioned comprehensive evaluation of dairy farming, such as dairy welfare, transportation elements, and government regulations, were not considered in this paper.

The methodological approaches in this paper also can be used in other research such as comparative advantages of planting, comparative advantages of other animal husbandry, and comparative advantages of industry. In the future, the comparative advantages of dairy farming in all provinces or municipalities in China should be carried out with considering more indexes. Moreover, the comparative advantages of dairy farming should be studied at the city scale or county scale to improve the accuracy of research results.

CRediT authorship contribution statement

Bojie Yan: Conceptualization, Methodology, Software, Investigation, Writing - original draft. **Yaxing Li:** Validation, Formal analysis, Visualization, Software. **Yanfang Qin:** Conceptualization, Methodology, Visualization, Software. **Jingjie Yan:** Resources, Writing - review & editing, Supervision, Data curation. **Wenjiao Shi:** Resources, Formal analysis, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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