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Success Factors of Biotechnology Industry Based on Triangular Fuzzy Number

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Abstract Based on the theory of competitive advantage and value chain, this paper establishes the indicator system, and develop the strategic framework using the fuzzy Delphi method. Then the triangular fuzzy number model is established using Fuzzy Analytic Hierarchy Process, and the key factors influencing biotechnology industry are extracted. The results show that in terms of weight, the key factors influencing the success of biotechnology industry are sequenced as follows: "open innovation capacity", "quality and cost control ability", "advanced customer-oriented product manufacturing capacity", "technology R & D personnel's capacity", "brand image building capacity", "logistics and sales capacity", "grasping the market demand trends". The manufacturers and government decision-making body can use this as the basis, to promote the development of the biotechnology industry.

Key words Triangular fuzzy number, Biotechnology industry, Evaluation of success factors

Biotechnology, also known as bio-engineering, established on the basis of the molecular biology, is the practical technology for creating new biological types or new biological function, and the product of combination of modern biological science and engineering technology. Specifically, bio-engineering technology includes transgenic plant and animal biotechnology, crop molecular breeding technology, nano-biotechnology, and biological treatment of important diseases. The term itself is largely believed to have been coined in 1919 by Hungarian engineer Karl Ereky. In the late 20th and early 21st century, biotechnology has expanded to include new and diverse sciences such as genomics, recombinant gene technologies, applied immunology, and development of pharmaceutical therapies and diagnostic tests. At present, the world's biotechnology development has entered the initial stage of mass industrialization, and the booming bio-medicine, bio-agriculture, bio-energy, bio-manufacturing and other fields are making the biological industry become a new leading industry in the world economy in succession to the information industry. It can be predicted that the future biotechnology will lead the global economy, to create huge economic opportunities and benefits that can not be imagined. The application of the global emerging biotechnology gradually combines agriculture with medicine, food, environmental protection and other industries, which opens up new application areas for agricultural activities and creates new industry. Biotechnology has exerted a revolutionary impact on agricultural development. With the rapid development of agricultural biotechnology, the Chinese agriculture will face many new challenges in the future.

Potter once pointed out that the basic unit for the analysis of national competitive advantage should be "industry" rather than "nation"[1]. So under the new pattern of the world's industrial structure, all countries, especially the developed countries are making great efforts to adjust their industrial structure to obtain greater benefits. Aaker also pointed out that only when one enterprise seized the key factors for the industry success can it create sustainable competitive advantage[2]. Since joining the WTO, the competitive pressure of imports of agricultural products on China's agriculture has been increasing. There are many factors affecting the competitive advantage of the industry, so we should generalize and clarify a variety of factors by the analytic hierarchy process in accordance with different levels, and make a molehill out of a mountain, to provide reference for decision making. In order to further express the fuzziness and uncertainties in thinking, this paper uses the fuzzy Delphi method and Fuzzy Analytic Hierarchy Process to integrate experts and scholars' recommendations on the development of biotechnology industry based on Porter's value chain theory. By the model data analysis, the key factors concerning the competitiveness of the biotechnology industry are extracted to provide reference for the industry and the decision-making body, so as to promote the rapid development of the biotechnology industry, and ensure the competitive advantage.

1 Competitive advantage and the value chain theory

Aaker believes that if we want to create the competitive advantage of enterprises, it is necessary to build lasting competitive advantage[2]. Sustainable competitive advantages must have the following three characteristics: (1) Sustainable competitive advantage is a competitive advantage significantly different from other competitors; (2) Sustainable competitive advantage must cover the critical success factors of the entire industry; (3) Sustainable competitive advantage must be able to adapt to changes in the environment as well as the response of competitors.

Porter developed the "value chain" theory for the analysis and evaluation of competitive advantage[3]. A value chain is a

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chain of activities that a firm operating in a specific industry performs in order to deliver a valuable product or service for the market. The concept comes from business management and was first described and popularized by Michael Porter in his 1985 best-seller, *Competitive Advantage*: *Creating and Sustaining Superior Performance*. Value activities can not only create value for customers, but also create value and profits for the company. Each stage in Fig. 1 contributes to the establishment of the competitiveness and competitive advantage. The purpose of the value chain analysis is to reduce costs and improve the image and value of the product in the minds of customers. Any industry is composed of a series of value activities. The acquisition and maintaining of competitive advantage not only need to have outstanding value chain, but also need to have the coordination of the entire value system of the industry. The value system of the industry includes suppliers, manufacturers, distributors, and customers.

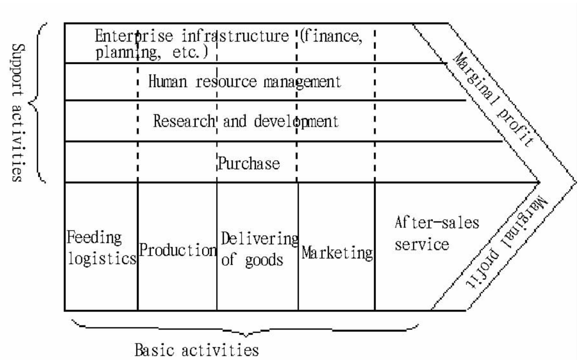

Fig. 1 Porter value chain

2 Research methods

The study uses the concept of fuzzy theory, the fuzzy Delphi method and the Fuzzy Analytic Hierarchy Process as the methods for research and analysis, and filters out the key factors for enhancing the competitive advantage of biotechnology industry in China. In the first phase, the expert questionnaires using fuzzy Delphi method are issued, to establish the strategic framework and various evaluation indicators. In the second phase, the weight relationship between indicators is obtained by the expert questionnaires using Fuzzy Analytic Hierarchy Process. Finally, according to the study results, the competitive advantage is derived and development strategies are proposed for the decision making of manufacturers and government.

2.1 Basic principles of fuzzy Delphi method The Delphi method is a structured communication technique, originally developed as a systematic, interactive forecasting method which relies on a panel of experts. In the standard version, the experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. It is believed that during this process the range of the answers will decrease and the group will converge towards the "correct" answer. Finally, the process is stopped after a pre-defined stop criterion (*e.g.* number of rounds, achievement of consensus, stability of results) and the mean or median scores of the final rounds determine the results. Other versions, such as the Policy Delphi, have been designed for normative and explorative use, particularly in the area of social policy and public health. In Europe, more recent web-based experiments have used the Delphi method as a communication technique for interactive decision-making and e-democracy. Delphi is based on the principle that forecasts (or decisions) from a structured group of individuals are more accurate than those from unstructured groups. This has been indicated with the term "collective intelligence". The technique can also be adapted for use in face-to-face meetings, and is then called mini-Delphi or Estimate – Talk – Estimate (ETE). Delphi has been widely used for business forecasting and has certain advantages over another structured forecasting approach, prediction markets.

2.2 Questionnaire design At the first stage of the design of the questionnaire, the expert questionnaire using the fuzzy Delphi method is based on the previously established preliminary architecture, to assess the appropriateness and importance of various indicators. The content of the questionnaire is divided into the basic data, filling instructions and questionnaire theme. Level 0 – 10 is adopted for scoring, and the higher, the more important. As for all evaluation indicators in the questionnaire, experts can fill in the appropriate score according to their personal views and provide recommendations.

The design of the questionnaire at the second stage will screen out the possible success factors based on the analysis results of the first stage questionnaire, to establish the second stage expert questionnaire using Fuzzy Analytic Hierarchy Process. The questionnaire content is mainly divided into sequencing of importance of assessment criteria and pairwise comparison of relative importance of the assessment criteria. Using assessment scale 1 – 9, and pairwise comparison, let expert complete the questionnaires.

3 Results and analysis

3.1 Questionnaire analysis based on triangular fuzzy number and the Delphi method The fuzzy Delphi method is to introduce the fuzzy theory in the general Delphi method, use triangular fuzzy number method to integrate expert's opinions, and use gray correlation degree to judge whether the expert's opinions reach convergence. Experts give a possible interval value for each assessment item, respectively. The minimum value in the interval value signifies the experts' conservative estimate of quantified fraction of the evaluation indicator, while the maximum value in the interval value signifies the experts' optimistic estimate of quantified fraction of the evaluation indicator. All experts' conservative estimate and optimistic assessment of each assessment item is analyzed. The extreme values more than 2 times of the standard deviation are estimated. The minimum value C_L^i, geometric mean C_M^i and maximum value C_U^i in the conservative estimates not eliminated are calculated; the minimum value O_L^i, mean O_M^i and maximum value C_U^i in the optimistic assessment are also calculated. Thus the triangular fuzzy number of conservative estimate and optimistic assessment of each evaluation indicator i is established, respectively:

$C^i = (C_L^i, C_M^i, C_U^i)$

$O^i = (O_L^i, O_M^i, O_U^i)$

(1) There is no gray fuzzy space: If $C_U^i \leqslant O_M^i$, then overlapping does not exist between triangular fuzzy numbers, indicating that there is consensus in the interval of experts and scholars. For the assessment item i, all the experts' conservative estimate has reached unanimity. Similarly, all the experts' optimistic assessment has reached consensus. So, the basic model is as follows:

$G^i = (O_M^i + C_M^i)/2$

(2) There is gray fuzzy space, but there is little divergence between experts: If $C_U^i > O_L^i$, it indicates that overlapping exists between triangular fuzzy numbers. And when the gray fuzzy space $Z^i = C_U^i - O_L^i$ is smaller than the mean of experts' conservative estimate and optimistic assessment of the assessment item $M^i = O_M^i - C_M^i$, it indicates that when the tiny gray fuzzy space exists, there is little difference between the experts giving extreme views and other experts and scholars, so the opinion divergence is not diffused. Therefore, we make importance extent value of consensus i G^i equal to gray fuzzy space of triangular fuzzy number for MIN operation to get fuzzy set $F^i(x_j)$. The calculation model is as follows:

$F^i(\chi_i) = \{\int_{\chi} min[C^i(\chi_i), O^i(\chi_j)]dx\}$

$G^i = \{\chi_j max\mu_{F^i}(\chi_j)\}$

(3) There is gray fuzzy space, but there is great divergence between experts: If $C_U^i > O_L^i$, it indicates that overlapping exists between triangular fuzzy numbers. And when $Z^i = C_U^i - O_L^i$ is greater than $M^i = O_M^i - C_M^i$, there is fuzzy area without consensus in the interval of experts and scholars' views, that is, there is great difference between the experts giving extreme views and other experts and scholars, resulting in diffusion of opinion divergence. Therefore, it is necessary to provide such evaluation not converged to expert for reference, and repeat the above work until all assessment items achieve convergence and the importance value of experts' consensus G^i can be calculated. So the higher the G^i, the higher the degree of consensus between experts.

3.2 The questionnaire analysis based on Fuzzy Analytic Hierarchy Process This study adopts Fuzzy Analytic Hierarchy Process as a method to calculate the weight relationship and importance degree of various assessment indicators. The fuzzy theory is introduced into Saaty's analytic hierarchy process[4] for the weight appraisal and importance sequencing, to sum up more rigorous scientific key competitiveness factors. This model is based on the research results of Buckley[6], Robbins[6] and other research scholars. By calculating various levels of consistency ratio and overall level of consistency ratio hierarchy, we can judge whether the entire hierarchy is consistent.

(1) Establishing hierarchical structure. According to evaluation indicators screened using the fuzzy Delphi method, the hierarchical structure with the number of elements in each level not more than seven is established.

(2) Establishing the pairwise comparison matrix. Through questionnaires, we can derive the relative importance of expert K in layer L to two evaluation indicators i, j in layer $L+1$, thereby establishing the pairwise comparison matrix A, $A = [\alpha_{ij}]$.

(3) Establishing the triangular fuzzy number model. According to the fuzzy Delphi method, triangular fuzzy number is established, and fuzziness of expert's views of the relative importance between two elements is integrated. The model and algorithm steps are as follows: $\tilde{\alpha}_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij})L-R$, $\alpha_{ij} \leqslant \delta_{ij} \leqslant \gamma_{ij}$, $i, j = 1, 2, \cdots, n$

$\alpha_{ij} = Min(B_{ijk}),\ k = 1, 2, \cdots, n$

$\delta_{ij} = (\prod_{k=1}^{n} B_{ijk})^{1/n}$

$\gamma_{ij} = Max(B_{ijk}),\ k = 1, 2, \cdots, n$

where $\tilde{\alpha}$ is triangular fuzzy number; α_{ij} is the minimum value of sub-indicator j under indicator i; δ_{ij} is the geometric mean of sub-indicator j under indicator i; γ_{ij} is the maximum value of sub-indicator j under indicator i; B_{ij} is the subjective view of expert K on the relative importance of attribute i, j; $L-R$ is the fuzzy interval of fuzzy triangular number.

(4) Establishing fuzzy positive inverted value matrix. Triangular fuzzy number is established, and it is used to express the assessment experts' view fuzziness, to establish fuzzy positive inverted value matrix $\tilde{A}$.

$$\tilde{A} = [\tilde{\alpha}_{ij}] = \begin{bmatrix} \tilde{\alpha}_{11} & \tilde{\alpha}_{12} & \cdots & \tilde{\alpha}_{1n} \\ \tilde{\alpha}_{21} & \tilde{\alpha}_{22} & \cdots & \tilde{\alpha}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\alpha}_{n1} & \tilde{\alpha}_{n2} & \cdots & \tilde{\alpha}_{nn} \end{bmatrix},\ i, j = 1, 2, \cdots, n$$

$\tilde{\alpha}_{ij} = [\alpha_{ij}, \delta_{ij}, \gamma_{ij}],\ \tilde{\alpha}_{ij} \times \tilde{\alpha}_{ji} \approx,\ \forall_{ij} = 1, 2, \cdots, n$

(5) Testing the consistency of fuzzy matrix $\tilde{A}$.

$\tilde{\alpha}_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij}),\ \alpha_{ij}, \delta_{ij}, \gamma_{ij},\ \in = 1, 2, \cdots, 9$

$\tilde{\alpha}_{ji} = (\tilde{\alpha}_{ij})^{-1} = \gamma_{ij}^{-1}, \delta_{ij}^{-1}, \alpha_{ij}^{-1}$

(6) Calculating the fuzzy weight of fuzzy positive inverted value matrix.

$\tilde{Z}_i = [\tilde{\alpha}_{if} \otimes \cdots \otimes \tilde{\alpha}_{in}]^{\frac{1}{n}},\ \forall_i, j = 1, 2, \cdots, n$

$\tilde{W}_i = \tilde{Z}_i \otimes (\tilde{Z}_1 \otimes \cdots \tilde{Z}_n)^{-1}$

$\tilde{\alpha}_1 \oplus \tilde{\alpha}_2 \cong (\alpha_1 \times \alpha_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2)$

$Z_1^{-1} = (\gamma_1^{-1}, \delta_1^{-1}, \alpha_1^{-1})_{L-R}$

$\tilde{\alpha}_1^{\frac{1}{n}} = [\alpha_1^{\frac{1}{n}}, \delta_1^{\frac{1}{n}}, \gamma_1^{\frac{1}{n}}]$

$\tilde{Z}$ is the geometric mean of the triangular fuzzy number.

(7) Defuzzification. The weight of each factor and evaluation indicators is fuzzy number, so we must use the defuzzification process to calculate the single fuzzy weight value. This research adopts the center of gravity method, and the algorithm is as follows:

$$W_i = \frac{W_{\alpha i} + W_{\delta i} + W_{\gamma i}}{3}$$

(8) Standardization. For the convenience of comparing the importance of different levels of indicators and secondary evaluation indicators, the weight values are standardized to make the sum equal to 1. The algorithm is as follows:

$$NW_i = \frac{W_i}{\sum_{i=1}^{n} W_i}$$

3.3 Questionnaire analysis results Through survey and research, model establishment and calculation, Fuzzy Analytic Hierarchy Process and MATLAB are used to deal with the second phase of the questionnaires. First triangular fuzzy number is used to establish the fuzzy positive inverted value matrix coupled with various experts' clear value for the test of matrix consistency. The results show that C. I. and C. R. values of the competitiveness enhancement of the biotechnology industry are less than or equal to 0.1, in line with Saaty's acceptable error range[4], so the judgment of experts at all levels is consistent. In addition, from the point of view of the overall evaluation, C. R. H. is 0.06, in line with C. R. H < 0.1, indicating that the consistency of the overall level of the study is acceptable. Therefore, the weight of various evaluation indicators in their respective level is analyzed (local priority), and then global priority is derived. Finally, the comprehensive sequencing is conducted based on the absolute weight value, and the sequencing results of importance are shown in Table 1.

Table 1 The weight and importance sequencing of biotechnology industry success factors

The first level		The second level				The third level			
Level	Absolute weight	Evaluation indicators	Level weight	Absolute weight	Sequencing of importance	Evaluation indicators	Level weight	Absolute weight	Sequencing of importance
Main operating factors	0.597	Production performance	0.695	0.714	1	Ability to innovate upon manufacturing process	0.203 2	0.016 2	20
						Advanced customer-oriented product manufacturing capacity	0.350 0	0.164 7	3
						Quality and cost control ability	0.310 9	0.172 3	2
		Grasping marketing and market opportunities	0.327	0.236	3	Grasping the market demand trends	0.275 9	0.049 5	7
						Brand image capability	0.263 0	0.067 4	5
						Logistics and sales capacity	0.299 8	0.052 3	6
						After-sales service capacity	0.173 7	0.019 4	17
Key support factors	0.425	R & D capacity	0.410	0.475	2	Intellectual property acquisition and management capability	0.100 2	0.018 3	18
						Key technology R & D capacity	0.201 1	0.031 7	10
						Technology integration and innovative application capability	0.247 9	0.023 9	14
						Open innovation capacity	0.321 4	0.210 1	1
						Technology integration and knowledge management capability	0.160 6	0.016 6	19
						New technology research and risk management capability	0.213 8	0.039 5	8
		Procurement and enterprise infrastructure	0.129	0.172	4	Financing capacity	0.172 1	0.025 5	13
						Basic core equipment acquisition capability	0.460 5	0.031 1	11
						High quality product certification system building capability	0.302 6	0.022 7	15
		Human resources	0.287	0.124	5	Reasonable and scientific talent structure	0.194 4	0.030 1	12
						Sound personnel training system	0.197 8	0.021 2	16
						Technology R & D personnel's capacity	0.276 5	0.149 1	4
						Technology research and development efficiency	0.351 9	0.033 2	9

From Table 1, experts believe that "production performance" ranks first in the five evaluation indicators at the second level, with the weight value of 0.714, followed by "R & D capacity" with the weight value of 0.475, "grasping marketing and market opportunities" with the weight value of 0.236, "procurement and enterprise infrastructure" with the weight value of 0.172, and "human resources" with the weight value of 0.124. Due to the late start of China's biotechnology industry, experts believe that "production performance", "R & D capacity" and other major events play a more significant role than "grasping marketing and market opportunities" and "human resources" in improving the competitiveness of the biotechnology industry.

In addition, in the key factors improving the competitiveness of the biotechnology industry, experts believe that "open innovation" is the most important in the 20 assessment indicators at the third level, with the weight value of 0.210 1, followed by "quality and cost control ability" with the weight value of 0.1723, "advanced customer-oriented product manufacturing capacity" with the weight value of 0.164 7 , "technology R & D personnel's capacity" with the weight value of 0.149 1, "brand image building capacity" with the weight value of 0.067 4, "logistics and sales capacity" with the weight value of 0.052 3, "grasping the market demand trends" with the weight value of 0.049 5, "new technology research and risk management capability" with the weight value of 0.039 5, and "technology research and development efficiency" with the weight value of 0.033 2.

In terms of selection of the number of critical success factors, based on Daniel's views on critical success factors in competitiveness[7], this study believes that in most industries, there are usually three to six factors that determine success. However, the weight values of indicators ranking sixth and seventh do not differ much, and thus this study uses LSD test again to distinguish and sequence. The results show that the difference between them is under 5%, but there is significant difference between them and indicator ranking eighth. Therefore, the study selects the top 7 factors in terms of the weight value as the key factors for enhancing the competitiveness of biotechnology industry ("open innovation capacity", "quality and cost control ability", "advanced customer-oriented product manufacturing capacity", "technology R & D personnel's capacity", "brand image building capacity", "logistics and sales capacity", "grasping the market demand trends").

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vegetable consumers mostly live in the city. On the other hand, the suburban land is largely used in industry and real estate construction in China. Vegetable production prolongs the distance between vegetable production and retail and also accelerates the lack of communication between farmers and markets, which results in high vegetable price indirectly. The key to isolation between vegetable production area and retail area lies in the market. The output increase doesn't necessarily lead to increasing in vegetable retail price. In order to stabilize the vegetable market, it is urgent to adjust vegetable output and explore more ways to sell products.

Thirdly, government's support. While the Chinese government continues to provide vegetable subsidy and insurance policy, which guarantee the benefit of farmers, effective measures to manage vegetable price in foreign countries can be applied, such as price intervention in Europe.

5 Discussion

The current studies of vegetable price mainly focused on the comparison of price itself. Based on such analysis, the vegetable price and residents' consumption index was connected together to discuss the relation between vegetable price and urban consumption, and the rapid increase of vegetable price would directly affect people's normal life. The conclusion in this paper maybe cannot be applied to all markets, but in the future, the vegetable will be divide more systematically, which makes the study result more meaningful.

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