ISAHP 2005, Honolulu, Hawaii, July 8-10, 2003

Choosing Promising Agbio Industry Areas by Using Fuzzy Multiple Criteria Decision Making Model

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Keywords: Agricultural biotechnology, AHP, fuzzy theory, fuzzy multiple criteria decision making

Summary: *Following in the wake of medical biotechnology, agricultural biotechnology (AgBio) is slated to become a key area of development in the biotechnology industry. Because agricultural biotechnology is closely connected with food, health, and resource technology industries, many countries are investing heavily in terms of both funding and talent to enhance their international competitiveness in this field. This research study was designed using the fuzzy multiple criteria decision making (FMCDM) methodology combining analytic hierarchy process (AHP) and fuzzy theory and holding a specialists' conference to decide promising AgBio products with international competitiveness for use in guiding industrial development strategies and the allocation of R&D resources. The results show that the FMCDM model can effectively summarize the views of AgBio specialists for the purpose of selecting promising target industries. The research process was also used to explore the various target industries and assess key issues such as the causal relationship between criteria and industries' degree of development. Beyond helping decision-makers formulate policies and allocate resources, this information is also provided as a research reference in connection with market surveys and industrial development trends, etc.*

1. Introduction

Like medicine, agriculture is intimately linked with human life. The tremendous progress made in biotechnology over the last few years has led to many groundbreaking developments in agricultural biotechnology (AgBio). It is expected that AgBio will join the mainstream of biotechnology in the wake of medical biotechnology, and many countries are upbeat about this area that combines food, health, and resource sciences industries. Nevertheless, because the target industries that could be developed are many as well as vastly complex and countries have limited financial and human resources, the question of how to objectively, fairly, and effectively select and assign priority to target industries possessing international competitiveness is a very important issue. AgBio products and technologies involve both plants and animals, while subareas include agriculture, forestry, fishing, and animal husbandry. Since an industry's core competence is derived from many key factors connected with R&D, manufacturing, mass production, and sales in the industry value chain, it is difficult to use a single criterion to assess the

[1] I am especially grateful to the Taiwan Institute of Economic Research (TIER). The main sources of funding for this study's AHP questionnaire survey and specialists' conference were the NSC "National Science and Technology Program for Agricultural Biotechnology: Stage III Plan – AgBio Industrialization Strategic Plan Research Projects" research grant (Project No. NSC 93-2317-B-301-001) and a Council of Agriculture "Agricultural Biotechnology Industrialization Promotion Strategy and Promising Product Direction Analysis Program" research grant (NSC Review No. 93210117 C 040201a225000) received by TIER in 2004. I (Yen-Ni Chang) was employed concurrently with my primary position as an assistant researcher at TIER during 2004, and I was also the main research worker in charge of the aforementioned AHP questionnaire survey.
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potential of target industries. A further challenge is that appropriate scientific assessment methods must be employed to objectively evaluate all specialist views while preserving the specialists' subjective uniqueness.

This study used a fuzzy multiple criteria decision (FMCDM) model to effectively resolve the aforementioned problems. The study's goal was to assess the most promising AgBio target industries, and enable specialists in different areas to achieve a consensus and thereby evaluate the country's development priorities. The FMCDM model employed in this study was adopted from ideas proposed by Bellman and Zadeh in 1970. After many revisions, the final research design incorporated the specialist group method, use of the analytic hierarchy process (AHP) to derive criteria weights (Satty, 1977), fuzzy theory (Zadeh, 1965, 1975) and the use of multiple criteria decision making (MCDM) to evaluate and rank different alternatives (Bohanec et al, 2000). It was felt that this design provided a rigorous and objective method of analyzing the views of AgBio experts concerning potential target industries.

The results of this study show that the FMCDM model can effectively summarize the views of AgBio specialists and select the most promising target industries. The second section of this paper introduces the research method's theoretical background, the third section gives an account of the research model, the fourth section explains and discusses the research results, and the fifth section presents conclusions.

2. Theoretical Background of Research Method

Conventional assessment methods such as the minimum cost method, the maximum profit method and cost effectiveness analysis can be used to assess and assign priority to alternatives in simple environments or when considering only a straightforward decision-making problem. Conventional assessment methods are not appropriate means of determining a solution when the decision-making environment involves complex aspects and multiple criteria, and when there are many types of mutually-linked information (Bohanec et al, 2000; Teng and Tzeng, 1996; Tang and Tzeng, 1999) AgBio industry encompasses many fields and items, and the assessment of a particular field's potential may involve such complex aspects as technology, the industry environment, and the legal system. Because of the many criteria involved and the different perceptions of specialists in different areas, this study has employed the FMCDM method proposed by Bellman and Zadeh in 1970 to construct an FMCDM model for assessing the potential of AgBio industries.

The FMCDM model's theoretical roots include AHP and fuzzy theory. Because of this, we provide a simple introduction to these two types of research methods. AHP is a fair and objective assessment approach proposed by Prof. Saaty of the University of California in 1971. AHP is usually applied to decision-making problems involving uncertain situations and containing multiple assessment criteria. Its most notable feature is the use of a multilayer structure to systematically link influencing factors with complex mutual relationships. The pairwise comparison of factors can ease the burden on decision-makers and ensure that their intentions can be clearly expressed. Furthermore, the collective decision making process facilitates the clear and systematic integration and analysis of scholars' views, increasing the effectiveness and reliability of assessment, and presenting the results in numerical units. Beyond clarifying the relative importance and rank of different factors, AHP can also establish a weight system and apply it to resource allocation, investment portfolios, and prediction, etc. with very good effectiveness. AHP is a fair and scientific method that takes customers into consideration and reflects and summarizes specialists' opinions. In short, use of the AHP method facilities determination of the best option via the assessment of multiple criteria.

Fuzzy theory provides experts with a flexible decision-making environment. An observer often cannot assign a precise number as a score for a certain event, but can only specify a range of numbers. Taking this study as an example, not every specialist necessarily considered "very good performance" of an industry with regard to a certain criterion to be 100 points; some may have considered anything in the range of between 80 points and 100 points to be very good performance. This type of variation based on differences in individual perception is reflected in fuzzy theory. We hoped that the selection process would preserve specialists' subjective and flexible scoring of each industry, and thereby uncover the unique nature of each industry relative to different assessment criteria.

Combining AHP with the fuzzy multiple criteria decision making (FMCDM) model can enable the

resolution of problems with multi-attribute structures. This type of problem is not amenable to decision making based on a single assessment element; problem characteristically has multiple goals or attributes, and contradictions or conflicts may exist between different criteria, or the assessment criteria are quantified in different units, or the decision-maker may have to select the optimal program from a limited number of alternatives. AHP and the FMCDM model can be applied to any problem in such areas as policy, investment portfolios, R&D product, and transportation alternatives where there are many criteria and where an alternative must be selected or an order of priority determined to meet multiple goals. Much relevant literature on this type of decision making has been published since the 1970's, and domestic and foreign industrial research organizations used this method to determine the order of priority of R&D plans or technological programs and thereby allocate manpower resources in the most effective manner. Based on the foregoing theoretical background of the research method, we next construct a research model for selecting the country's most promising AgBio industries.

3. Establishment of a Research Model

The FMCDM model's basic constituent elements consist of combinations of alternatives, combinations of criteria, the performance values resulting from the implementation of each alternative, and information on decision-makers' preferences. As a result, the model and its constituent elements had to be designed to achieve the desired goal of selecting promising AgBio industries. We first clearly defined the research goal, assessment aspects, assessment criteria, and the target industries that could be selected (the alternatives). After establishing this promote, we then performed pairwise comparison of the weights of each assessment criterion, and assigned a score to each target industry. We multiplied the scores by the weight of each criterion, and summed the performance values for all criteria. The resulting values are the overall performances of each target industry; the ranking of industries by overall performance can guide the allocation of resources. This study takes Taiwan's "National Science and Technology Program for Agricultural Biotechnology: Stage III Plan – AgBio Industrialization Strategic Plan Research Projects" as an example. The program office provided 20 target industries (alternatives) and this project hired 30 specialists from industry, government, academia, and the research community to perform selection tasks. The following is an overview of the research model framework.

After several thoroughgoing discussions, the specialists finally decided to take "industry environment," "industrialization capability," "policies and laws," and "derivative value" as the four assessment aspects (the first layer), and derived 16 assessment criteria (the second layer) from these aspects. The members of the planning committee jointly formulated 20 target industries (the third layer) that also could be regarded as niches. The research framework was as shown in the following diagram (see Fig. 1); the various assessment aspects and criteria are explained as follows:

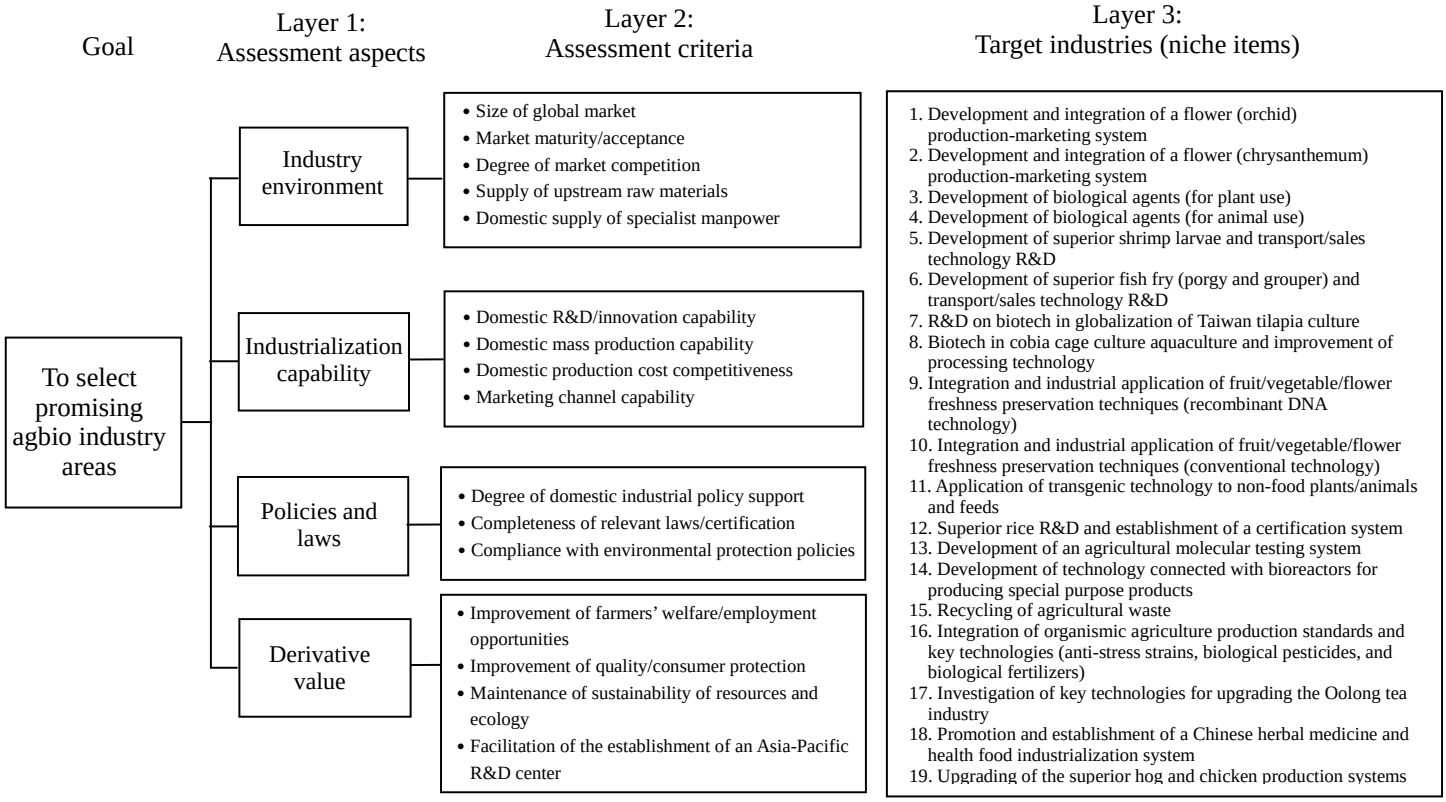
3.1 Industry Environment

The assessment criteria under the aspect of "industry environment" incorporate economic factors such as Porter's "five forces" theory, up- and downstream value chains, and market supply and demand. The five assessment criteria include: (1) size of global market, (2) market maturity/degree of acceptance, (3) degree of market competition, (4) supply of upstream raw materials, and (5) domestic supply of specialist manpower.

3.2 Industrialization Capability

The assessment criteria under the aspect of "industrialization capability" seek to analyze the core values (which may consist of flagship products, key technologies, platforms or integration systems) of the industry in question, and take into consideration all elements from R&D, manufacturing, mass production through marketing, while incorporating the concept of cost. These criteria therefore include (1) domestic R&D/innovation ability, (2) domestic mass production capability, (3) domestic production cost competitiveness, and (4) marketing channel capability.

Fig. 1. Structure of AHP Model for Selecting Promising AgBio Industries



3.3. Policies and Laws

The assessment criteria under the aspect of "policies and laws" primarily address factors that may assist the growth of the industry in question, and seek to determine whether there is policy support, whether laws and regulations are comprehensive, and whether there may be violation of environmental protection principles. Assessment criteria include (1) degree of domestic industrial policy support, (2) completeness of relevant laws/certification, and (3) compliance with environmental protection policies.

3.4 Derivative Value

The assessment criteria under the aspect of "derivative value" primarily examine the social benefit brought by the industry in question, such as whether it promotes farmers' welfare and increases employment, whether the products increase safety, and whether the industry contributes to making Taiwan an Asia-Pacific AgBio R&D center. Assessment criteria include (1) improvement of farmers' welfare/employment opportunities, (2) improvement of quality/consumer protection, (3) maintenance of sustainability of resources and ecology, and (4) facilitation of the establishment of an Asia-Pacific R&D center.

To preserve the specialists' subjective scoring of each industry with relation to the foregoing criteria, we gave the specialists five performance levels (very good, good, average, poor, very poor) with which to score each criterion. We also allocated them to set upper and lower limits, which was necessary to facilitate our subsequent calculation of each industry's performance value. We used the Expert Choice Pro 9.5 software package to process the questionnaire data, including calculation of the FMCDM

model's priority vector, consistency index, consistency ratio, and overall layer weight. We also employed Microsoft's Excel XP spreadsheet software to calculate the weight assigned to each assessment criteria by each specialist and the overall performance value of each target industry.

4. Selection Results and Discussion

After formulating the assessment goal, assessment aspects, assessment criteria, and target industries (alternatives) as described above, we asked the members of the planning committee to fill out questionnaires. A total of 28 questionnaires were returned, and an inspection of the specialists' degree of familiarity (average familiarity was 76.96%) was employed to confirm the committee members' ability to professionally assess the target industries.

4.1 Weighting of Assessment Aspects and Criteria

The results of the questionnaire survey (Table 1) indicate that the members of the specialist committee felt that "marketing channel capability" (10.82%)was the leading factor distinguishing promising industries, and this was followed by "R&D innovation ability"(10.25%), "completeness of relevant laws/certification "(9.94%), and "degree of domestic industrial policy support"(8.28%). This shows that the members of the specialists committee placed a relatively high degree of emphasis on the two assessment aspects of "industrialization capability"(31.65%) and "policies and laws" (25.46%).

Table 1 Weights Assigned to AgBio Target Industry Assessment Criteria

Assessment aspect	Assessment criteria	Weight percentage	Rank
Industry environment		21.54% (3)	
	Size of global market	3.75%	(16)
	Market maturity/acceptance	4.16%	(15)
	Degree of market competition	4.24%	(14)
	Supply of upstream raw materials	4.67%	(12)
	Domestic supply of specialist manpower	5.08%	(9)
Industrialization capability		31.65% (1)	
	Domestic R&D/innovation capability	10.25%	(2)
	Domestic mass production capability	4.28%	(13)
	Domestic production cost competitiveness	6.80%	(5)
	Marketing channel capability	10.82%	(1)
Policies and laws		25.46% (2)	
	Degree of domestic industrial policy support	8.28%	(4)
	Completeness of relevant laws/certification	9.94%	(3)
	Compliance with environmental protection policies	6.08%	(6)
Derivative value		21.35% (4)	
	Improvement of farmers' welfare/employment opportunities	4.84%	(10)
	Improvement of quality/consumer protection	6.05%	(7)
	Maintenance of sustainability of resources and ecology	5.96%	(8)
	Facilitation of the establishment of an Asia-Pacific R&D center	4.82%	(11)

4.2 Results of Comparing Promising AgBio Industries

After multiplying "assessment criteria weight" by "performance value" and summing the scores assigned by all committee members, the target industries were ranked as shown in Table 2. The joint specialists' selection process yielded a list of the five most promising industries. These were, in order, development and integration of an orchid production-marketing system (73.61), R&D on biotech in globalization of Taiwan tilapia culture (69.66), development of superior shrimp larvae and transport/sales technology R&D (68.95), promotion and establishment of a Chinese herbal medicine and health food

industrialization system (68.67), and development and integration of a chrysanthemum production-marketing system (67.26). There was an even distribution of plant and animal items among the top ten industries, each accounting for 50%.

Table 2 Rank of Promising AgBio Industries

Rank	Promising target industries	Score
1	Orchids	73.61
2	Taiwan Tilapia	69.66
3	Shrimp larvae	68.95
4	Chinese herbal medicines	68.67
5	Chrysanthemums	67.26
6	Cobia aquaculture	66.91
7	Fish fry (porgy and grouper)	66.46
8	Superior hogs and chickens	65.82
9	Fruit and vegetable freshness preservation (conventional technology)	65.64
10	Superior rice	65.59
11	Oolong tea	65.52
12	Organismic agriculture	64.12
13	Biological agents (for animal use)	62.84
14	Biological agents (for plant use)	62.18
15	Agricultural molecular testing	61.71
16	Waste recycling	60.92
17	Fruit and vegetable freshness preservation (recombinant DNA technology)	58.54
18	GMO	57.66
19	Bioreactors	57.55
20	Transgenic technology	56.25

Note: This table abbreviates the names of the industries; for instance, "development and integration of an orchid production-marketing system" is simplified as "orchids."

4.3 Analysis of High and Low Performance Criteria for Each Target Industry

In accordance with the assessment scores that each planning committee member gave to the criteria for each industry, each criterion was evaluated as either "high performance" (cumulative performance was very good or good) or is "low performance" (cumulative performance was very poor or poor). When the scoring results for all committee members were summed, the top three high performance criteria and bottom three low performance criteria for each industry were found to be as shown in tables 3 and 4; this information may serve to guide future development strategy decisions.

"Derivative value" was the most common highest criterion among the top three criteria for each industry. "Industry environment" was second, and "industrialization capability" and "policies and laws" were tied for third place. "Laws/certification" was the worst of the low performance criteria for 19 industries, however, which indicates that the members of the specialists committee consistently felt that the development of AgBio industry in Taiwan will require the strengthened planning of legal and certification systems.

4.4 Rank of Target Industries for Each Assessment Criterion

The members of the planning committee assigned a score to each industry relative to each criterion. Table 5 shows the top industries for each criterion in terms of their performance. We found that "orchids," "Chinese herbal medicine/health foods," "superior seedlings," "cobia cage aquaculture," "Taiwan tilapia," and "fruit and vegetable freshness preservation technology" had relatively good performance relative to all criteria. This information can provide decision-makers with another angle for thinking about development priorities, and can be used for strategic planning and analysis in conjunction with the selection results derived using the FMCDM model.

Table 3 Top Three "high performance" Criteria for Each Industry

Target industry	Three criteria with highest performance					
	First criterion	Score	Second criterion	Score	Third criterion	Score
Orchid production-marketing system	Size of market	7.407	Market maturity	7.037	R&D capability	7.037
Chrysanthemum production-marketing system	Market maturity	4.815	Asia-Pacific center	4.815	Raw materials supply	4.630
Biological agents (for plant use)	Maintenance of resources	4.615	Environmental protection	4.423	Quality improvement	4.423
Biological agents (for animal use)	Size of market	4.800	Quality improvement	4.200	Industrial policy	4.000
Shrimp larvae	Asia-Pacific center	6.458	Size of market	6.250	Quality improvement	6.042
Fish fry (porgy and grouper)	Asia-Pacific center	5.652	Quality improvement	5.435	Raw materials supply	4.783
Tilapia globalization	Industrial policy	5.625	Mass production capability	5.417	Farmers' welfare	5.208
Cobia cage aquaculture	Size of market	5.208	Asia-Pacific center	5.208	Quality improvement	5.000
Fruit and vegetable freshness preservation (recombinant DNA)	Mass production capability	5.800	Asia-Pacific center	4.800	Farmers' welfare	4.200
Fruit and vegetable freshness preservation (conventional)	Farmers' welfare	5.385	Quality improvement	4.808	Size of market	4.231
Use of transgenic technology in animal feed	Asia-Pacific center	3.846	R&D capability	3.269	Size of market	3.077
Superior rice	Quality improvement	6.000	Farmers' welfare	5.200	R&D capability	4.600
Agricultural molecular testing system	Asia-Pacific center	4.423	Size of market	4.231	Quality improvement	4.231
Bioreactors	Asia-Pacific center	5.000	Size of market	4.038	Quality improvement	3.462
Agricultural waste recycling	Environmental protection	5.370	Maintenance of resources	5.370	Quality improvement	3.519
Organismic agriculture	Maintenance of resources	5.769	Quality improvement	5.000	Environmental protection	4.615
Oolong tea industry upgrading	Quality improvement	5.870	Industrial policy	5.652	Asia-Pacific center	5.217
Chinese herbal medicine and health foods	Size of market	6,731	Asia-Pacific center	6.154	Market maturity	5.962
Superior hog and chicken production system	Quality improvement	5.833	Asia-Pacific center	5.417	Farmers' welfare	4.792
GMO assessment technology & certification	Asia-Pacific center	5.370	Quality improvement	5.185	Size of market	3.333

Table 4 Bottom Three "high performance" Criteria for Each Industry

Target industry	Three criteria with worst performance					
	Worst criterion	Score	Second worst criterion	Score	Third worst criterion	Score
Orchid production-marketing system	Laws/certification	1.111	Production cost	0.370	Industrial policy	0.370
Chrysanthemum production-marketing system	Laws/certification	1.296	Industrial policy	0.556	Environmental protection	0.556
Biological agents (for plant use)	Laws/certification	2.692	Market competition	1.154	Marketing channels	0.962
Biological agents (for animal use)	Laws/certification	2.200	Mass production capability	1.000	Marketing channels	1.000
Shrimp larvae	Laws/certification	1.458	Raw materials supply	0.625	Environmental protection	0.625
Fish fry (porgy and grouper)	Laws/certification	1.522	Environmental protection	0.652	Maintenance of resources	0.652
Tilapia globalization	Laws/certification	1.458	Production cost	0.625	Environmental protection	0.625
Cobia cage aquaculture	Laws/certification	1.667	Maintenance of resources	0.833	Environmental protection	0.625
Fruit and vegetable freshness preservation (recombinant DNA)	Laws/certification	3.600	Marketing channels	1.600	Industrial policy	1.400
Fruit and vegetable freshness preservation (conventional)	Laws/certification	1.538	Market competition	0.962	Production cost	0.769
Use of transgenic technology in animal feed	Laws/certification	4.808	Marketing channels	2.500	Market maturity	1.538
Superior rice	Laws/certification	1.600	Production cost	1.200	Size of market	1.000
Agricultural molecular testing system	Laws/certification	2.692	Market maturity	1.154	Production cost	1.154
Bioreactors	Laws/certification	3.462	Market competition	2.115	Market maturity	1.923
Agricultural waste recycling	Marketing channels	2.407	Laws/certification	1.852	Size of market	1.667
Organismic agriculture	Laws/certification	1.731	Marketing channels	0.962	Market competition	0.577
Oolong tea industry upgrading	Laws/certification	2.174	Environmental protection	1.087	Maintenance of resources	1.087
Chinese herbal medicine and health foods	Laws/certification	1.731	Production cost	0.769	Raw materials supply	0.577
Superior hog and chicken production system	Laws/certification	1.458	Production cost	1.042	Environmental protection	1.042
GMO assessment technology & certification	Laws/certification	4.630	Market competition	1.852	Market maturity	1.852

Table 5 Industry Rank for Each Assessment Criterion

Rank	Size of global market	Market maturity/acceptance	Degree of market competition	Supply of upstream raw materials
1	Orchids	Orchids	Chinese herbal medicines/health food	Orchids
2	Chinese herbal medicines/health food	Shrimp larvae	Orchids	Taiwan tilapia
3	Shrimp larvae	Chinese herbal medicines/health food	Taiwan tilapia	Fish fry (porgy and grouper)
4	Cobia	Chrysanthemums	Fish fry (porgy and grouper)	Chrysanthemums
5	Biological agents (for animal use)	Cobia	Shrimp larvae	Chinese herbal medicines/health food
6	Fish fry (porgy and grouper)	Taiwan tilapia	Cobia	Cobia
7	Fruit/vegetable freshness preservation (conventional technology)*	Fruit/vegetable freshness preservation (conventional technology)	Fruit/vegetable freshness preservation (conventional technology)	Oolong tea
8	Agricultural molecular testing*	Fish fry (porgy and grouper)	Fruit/vegetable freshness preservation (recombinant DNA technology)	Biological agents (for animal use)
9	Bioreactors	Superior hogs and chickens	Organismic agriculture	Shrimp larvae
10	Fruit/vegetable freshness preservation (recombinant DNA technology)	Biological agents (for plant use)	Oolong tea	Fruit/vegetable freshness preservation (conventional technology)
11	Biological agents (for plant use)	Superior rice	Superior rice	Superior hogs and chickens
12	Taiwan tilapia**	Biological agents (for animal use)	Superior hogs and chickens	Biological agents (for plant use)
13	Superior hogs and chickens**	Agricultural molecular testing	Transgenic technology	Superior rice
14	GMO	Organismic agriculture	Agricultural molecular testing*	Waste recycling
15	Organismic agriculture	Fruit/vegetable freshness preservation (recombinant DNA technology)	Bioreactors*	Agricultural molecular testing
16	Chrysanthemums	Oolong tea	Biological agents (for animal use)	Transgenic technology*
17	Transgenic technology	Bioreactors	Chrysanthemums	Organismic agriculture*
18	Superior rice	GMO	Biological agents (for plant use)	Fruit/vegetable freshness preservation (recombinant DNA technology)
19	Oolong tea	Waste recycling	GMO	Bioreactors
20	Waste recycling	Transgenic technology	Waste recycling	GMO

Note: *, **, and *** indicate that the adjacent industries had identical scores relative the assessment criterion in question. (continued on next page)

Table 5 Industry Rank for Each Assessment Criterion (continued)

Rank	Domestic supply of specialist manpower	Domestic R&D/innovation capability	Domestic mass production capability	Domestic production cost competitiveness
1	Orchids	Orchids	Orchids	Orchids
2	Chinese herbal medicines/health food	Shrimp larvae	Fruit/vegetable freshness preservation (recombinant DNA technology)	Taiwan tilapia
3	Shrimp larvae	Chrysanthemums	Taiwan tilapia	Cobia
4	Cobia	Chinese herbal medicines/health food	Chrysanthemums	Chinese herbal medicines/health food
5	Chrysanthemums	Superior rice	Shrimp larvae	Shrimp larvae
6	Superior hogs and chickens*	Taiwan tilapia*	Chinese herbal medicines/health food	Chrysanthemums
7	Taiwan tilapia*	Cobia*	Cobia	Fish fry (porgy and grouper)
8	Superior rice	Fish fry (porgy and grouper)	Fish fry (porgy and grouper)	Oolong tea
9	Fish fry (porgy and grouper)	Agricultural molecular testing	Superior hogs and chickens	Bioreactors
10	Agricultural molecular testing	Superior hogs and chickens	Oolong tea	Biological agents (for animal use)
11	Oolong tea	Oolong tea	Superior rice	Biological agents (for plant use)
12	Fruit/vegetable freshness preservation (conventional technology)**	Fruit/vegetable freshness preservation (recombinant DNA technology)	Biological agents (for animal use)	Agricultural molecular testing
13	Transgenic technology**	Transgenic technology	Bioreactors*	Superior hogs and chickens
14	Fruit/vegetable freshness preservation (recombinant DNA technology)	Fruit/vegetable freshness preservation (conventional technology)	Organismic agriculture*	Transgenic technology*
15	Waste recycling	Biological agents (for animal use)	Biological agents (for plant use)**	Organismic agriculture*
16	Bioreactors	Biological agents (for plant use)	Agricultural molecular testing**	Fruit/vegetable freshness preservation (recombinant DNA technology)**
17	Biological agents (for animal use)	Bioreactors	Fruit/vegetable freshness preservation (conventional technology)***	Superior rice**
18	Organismic agriculture	Organismic agriculture	Transgenic technology***	GMO
19	Biological agents (for plant use)	Waste recycling	Waste recycling	Fruit/vegetable freshness preservation (conventional technology)
20	GMO	GMO	GMO	Waste recycling

Note: *, **, and *** indicate that the adjacent industries had identical scores relative the assessment criterion in question. (continued on next page)

Table 5 Industry Rank for Each Assessment Criterion (continued)

Rank	Marking channel capability	Degree of domestic industrial policy support	Completeness of relevant laws/certification	Compliance with environmental protection policies
1	Orchids	Orchids	Oolong tea	Waste recycling
2	Shrimp larvae*	Chinese herbal medicines/health food	Fruit/vegetable freshness preservation (conventional technology)	Orchids
3	Taiwan tilapia*	Oolong tea	Shrimp larvae*	Organismic agriculture
4	Oolong tea	Taiwan tilapia	Superior hogs and chickens*	Biological agents (for plant use)
5	Chinese herbal medicines/health food	Chrysanthemums	Chinese herbal medicines/health food	Biological agents (for animal use)
6	Superior hogs and chickens	Superior rice	Chrysanthemums	Shrimp larvae
7	Cobia	Cobia*	Orchids	Chrysanthemums
8	Fish fry (porgy and grouper)	Shrimp larvae*	Superior rice	Agricultural molecular testing*
9	Chrysanthemums	Superior hogs and chickens	Taiwan tilapia**	Chinese herbal medicines/health food*
10	Superior rice	Fish fry (porgy and grouper)	Cobia**	Cobia
11	Fruit/vegetable freshness preservation (conventional technology)	Biological agents (for animal use)	Biological agents (for animal use)	Superior rice
12	Transgenic technology	Organismic agriculture	Waste recycling	Fruit/vegetable freshness preservation (conventional technology)
13	Biological agents (for animal use)	Waste recycling**	Fruit/vegetable freshness preservation (recombinant DNA technology)	Taiwan tilapia
14	Bioreactors	GMO**	Biological agents (for plant use)	GMO
15	Fruit/vegetable freshness preservation (recombinant DNA technology)	Biological agents (for plant use)	Fish fry (porgy and grouper)	Fish fry (porgy and grouper)**
16	Agricultural molecular testing**	Agricultural molecular testing	Organismic agriculture	Oolong tea**
17	Organismic agriculture**	Fruit/vegetable freshness preservation (recombinant DNA technology)	Transgenic technology***	Bioreactors
18	Biological agents (for plant use)	Fruit/vegetable freshness preservation (conventional technology)	Agricultural molecular testing***	Fruit/vegetable freshness preservation (recombinant DNA technology)
19	Waste recycling***	Bioreactors	GMO	Superior hogs and chickens
20	GMO***	Transgenic technology	Bioreactors	Transgenic technology

Note: *, **, and *** indicate that the adjacent industries had identical scores relative the assessment criterion in question. (continued on next page)

Table 5 Industry Rank for Each Assessment Criterion (continued)

Rank	Improvement of farmers' welfare/employment opportunities	Improvement of quality/consumer protection	Maintenance of sustainability of resources and ecology	Facilitation of the establishment of an Asia-Pacific R&D center
1	Fruit/vegetable freshness preservation (conventional technology)	Shrimp larvae	Organismic agriculture	Orchids
2	Orchids	Superior rice	Waste recycling	Shrimp larvae
3	Taiwan tilapia	Chinese herbal medicines/health food	Biological agents (for plant use)	Chinese herbal medicines/health food
4	Superior rice	Oolong tea	Biological agents (for animal use)	Fish fry (porgy and grouper)
5	Shrimp larvae	Superior hogs and chickens	Orchids	Superior hogs and chickens
6	Cobia*	Fish fry (porgy and grouper)	Agricultural molecular testing	GMO
7	Superior hogs and chickens*	Taiwan tilapia	GMO	Oolong tea
8	Fish fry (porgy and grouper)	GMO	Superior rice	Cobia*
9	Chrysanthemums	Orchids*	Chrysanthemums	Taiwan tilapia*
10	Chinese herbal medicines/health food	Cobia*	Fruit/vegetable freshness preservation (conventional technology)*	Bioreactors
11	Oolong tea	Organismic agriculture*	Chinese herbal medicines/health food*	Chrysanthemums
12	Fruit/vegetable freshness preservation (recombinant DNA technology)	Fruit/vegetable freshness preservation (conventional technology)	Fish fry (porgy and grouper)	Fruit/vegetable freshness preservation (recombinant DNA technology)
13	Organismic agriculture	Biological agents (for plant use)	Shrimp larvae**	Agricultural molecular testing
14	Waste recycling	Agricultural molecular testing	Taiwan tilapia**	Fruit/vegetable freshness preservation (conventional technology)
15	Transgenic technology	Biological agents (for animal use)	Bioreactors	Biological agents (for plant use)**
16	Biological agents (for animal use)	Fruit/vegetable freshness preservation (recombinant DNA technology)	Cobia***	Transgenic technology**
17	Biological agents (for plant use)	Chrysanthemums	Superior hogs and chickens***	Organismic agriculture**
18	Agricultural molecular testing	Waste recycling	Fruit/vegetable freshness preservation (recombinant DNA technology)	Biological agents (for animal use)
19	Bioreactors	Bioreactors	Oolong tea	Waste recycling
20	GMO	Transgenic technology	Transgenic technology	Superior rice

Note: *, **, and *** indicate that the adjacent industries had identical scores relative the assessment criterion in question.

5. Conclusions

AHP and the FMCDM model are an effective means of converting specialists' qualitative assessments into quantitative indicators, and enable the cross comparison of different criteria and industries. The following is a summary analysis of this study's findings: First, the members of the specialists committee consistently felt that the most important characteristics of an internationally competitive target industry are "marketing channel capability" (first place) and "R&D & innovation capability" (second place) under the aspect of "industrialization capability"; the next most important characteristics were considered to be "completeness of relevant laws/certification" (third place) and "degree of domestic industrial policy support" (fourth place) under the aspect of "policies and laws." Second, this study provides each industry a performance report with regard to the different assessment criteria, which will help determine which infrastructure items require improvement. Since many of the target industries are dissatisfied with the condition and performance of the legal environment, this aspect urgently requires improvement if Taiwan's AgBio industries are to develop smoothly. Third, this study's greatest contribution lies in its having brought together experts, industry representatives, and specialists in various AgBio fields for the first time under the "National Science and Technology Program for Agricultural Biotechnology" to discuss industry items encompassing agriculture, forestry, fisheries, and animal husbandry; plants and animals; and products, services, and up- and downstream system integration to facilitate selection tasks. The study placed balanced emphasis on the specialists' subjective judgment and objective assessment of each industry's overall performance relative to all assessment criteria. The resulting information allows the comparison of each industry's level of development and in-depth analysis of the various industries.

While the participating specialists made only a one-time selection, it would be extremely difficult to account exhaustively for all industry items, and sufficient manpower was ultimately not available. As a consequence, this study relied on the specialists' self-assessments of their familiarity towards each of the target industries to ensure that they were qualified to make professional assessments. The study further employed multi-group cross analysis in order to objectively express the specialists' industry performance scores. It is hoped that the results of this study will provide guidance to high-level decision-makers in industry, government, academia, and the research community. Finally, apart from this study's very successfully combined application of AHP and fuzzy theory, it should be mentioned that the assessment criteria took into consideration the theory of industry value chains and industry core competitiveness, etc., and reflected the influence of economic, social, and policy/legal factors. In addition, an effort was made to perform a rigorous, all-round assessment of scientific, economic, and social benefits. As a result, the study's findings may serve as a reference for the drafting of AgBio development strategies in other countries.

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