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Sustainable production systems of urban agriculture in the future: a case study on the investigation and development countermeasures of the plant factory and vertical farm in China

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Introduction: In recent years, innovative sustainable agricultural production technologies, including vertical farms and plant factories, have been developing rapidly around the world. The development of plant factories and vertical farms is currently receiving a lot of attention from Chinese academia and industry. However, the recognition and satisfaction of the government, producers, sales companies, and consumers are low, and their attitudes are mixed, mainly due to high pre-construction and post-operation costs, low comprehensive utilization of resources, low product diversity, low market share, high prices, and low core competitiveness, which limit its healthy and sustainable development. This paper designed a questionnaire from the perspectives of industrialization, commercialization, and sustainability in order to understand the respondents' level of awareness, doubts and concerns, purchase intentions and consumption expectations, as well as their trust and recognition of branded products in this new agricultural production system.

Method: To determine the diversity of respondents, this paper examines the group structure of participants from management, research and development, manufacturing, sales, consumers, regional development, and other industrial sectors. The survey was conducted using both face-to-face interviews and electronic questionnaires. As an online survey, the questionnaire was distributed to social groups through social media platforms. A total of 729 valid questionnaires were submitted. For the purposes of categorizing, enumerating, compiling statistics, and analyzing the questionnaires used in this study, descriptive statistics, multi-factor cross-analysis, and other statistical methods were employed. The social roles, functions, and interaction styles of various plant factory practitioners are examined from the perspective of social relationships, and pertinent development concepts and suggestions are proposed based on the survey results.

Results and conclusions: The study found that an increasing number of consumers are understanding and accepting this new form of plant production and are willing to purchase plant products from plant factories and vertical farming. Plant factories and vertical farms are widely regarded as one of the most important methods of future urban agricultural production. Awareness, purchase intent, price expectations, brand awareness, and price expectations of plant factories and vertical farms varied significantly by gender, age, education level, occupation, and income. In addition, there are numerous findings that provide governments, producers, marketers, managers, and consumers with great value and assistance.

Development recommendations: We should take the opportunity of developing plant factories to adjust the structure of the plant industry, enrich the "vegetable basket" of urban residents, increase the supply capacity of the market, enhance agricultural modernization and technological innovation, improve the quality of agricultural products from plant factories, strengthen the brand sales of plant products, and develop more functional plant products with high added value. Through the development of plant factories and vertical farms, we can improve the nutrition and healthy diet structure of citizens' diets, increase the modern plant industry's contribution to the national economy, and promote the comprehensive and sustainable development of the urban productive plant industry.

KEYWORDS

sustainable agriculture, plant factory, vertical farm, urban agriculture, precision agriculture, intelligent agriculture, facility agriculture

1. Introduction

1.1. Background analysis

Globally, by 2050, there will be 9.1 billion people on the planet, an increase of 34% from today. About 70% of those people will live in cities, up 21% from the current urban population, and the rate of urbanization will continue to increase (Food and Agriculture Organization, 2009). With the expansion of the global economy, urban dwellers' income levels will double, their consumption levels will dramatically rise, and price will no longer be the primary determinant of food consumption. However, food and vegetable production must be improved economically and efficiently in order to feed this larger, more urbanized, and more affluent population. It is estimated that in order to keep up with the rising consumption of food and vegetables, it will need to rise by at least 70% (Dias, 2015). Additionally, the Food and Agriculture Organization of the United Nations estimates that in 2019, before the COVID-19 pandemic outbreak, close to 690 million people worldwide—or 8.9% of the world's population—were experiencing food shortages (FAO, IFAD, UNICEF, WFP, and WHO, 2020). Localized hunger has become a more pressing issue as a result of the global spread of COVID-19 and successive regional calamities.

Faced with the growth of world population, the expansion of urban scale, the reduction of agricultural land, the shortage of food supply and the loss of agricultural labor force, human beings have to use more and more scarce cultivated land to support the growing population. It is crucial to enhance the working conditions for agricultural workers, the rate at which land is used, and the productivity of food crops. The only option for the sustainable and harmonious growth of the city will be to completely utilize the urban planting area, aggressively expand urban agriculture, and integrate urban agriculture into urban development in order to address the enormous daily food consumption of urban people. Urban agriculture (UA) (De Bon et al., 2010; Pearson et al., 2010; David, 2011; Tracey, 2011; Kozai, 2012; Specht et al., 2014; Lin et al., 2015; Michelon et al., 2019; Appolloni et al., 2020; Ola, 2020; Gómez-Villarino and Ruiz-Garcia, 2021; Marçal et al., 2021) refers to a variety of agricultural planting, breeding and related activities implemented in urban areas and surrounding suburbs. The plant factory (Goto, 2012; Kozai, 2013, 2019; Hu et al., 2014; Graamans et al., 2017, 2018) and the vertical farm (Besthorn, 2013; Despommier, 2013; Al-Chalabi, 2015; Benke and Tomkins, 2017; kaur and Chawla, 2021) are the new development direction of facility agriculture, urban agriculture, intelligent agriculture and modern agriculture, and the advanced mode of fully exploiting and utilizing urban space for facility agriculture production. It is an efficient way to resolve the conflict between the growth of the urban population, the expansion of the urbanization process, and the decline in the amount of arable land per person (Kozai, 2013; Langemeyer et al., 2021; Olvera-Gonzalez et al., 2021). The plant factory, as a high-end type of sustainable development of facility agriculture and urban agriculture (Kozai et al., 2019; Yang, 2019), has the characteristics of modernization and intellectualization and is a part of precision agriculture and intelligent agriculture (Hu et al., 2018). Their advent has changed how humans have farmed for thousands of years and offered a fresh approach to resolving the conflict between the world's population growth and the depletion of available land resources, as well as the current food crisis (Yamori et al., 2014; Kalantari et al., 2018). At present, many countries and regions are actively exploring and developing modern three-dimensional cultivation models to address the shortcomings of traditional agricultural production. Such as Japan, South Korea, Thailand, Singapore, China and Chinese Taiwan in Asia; the United States and Canada in North America; and Poland, Hungary, and the United Kingdom in Europe. Representative examples include Bowery Farming, Plenty, and Oishii Farm in the United States; Future Crops in the Netherlands; SMARTKAS in Hungary; Infarm in Germany; LettUs Grow in the United Kingdom; Techno Farm in Japan; Farmy in Malaysia; and China's Sanan Optoelectronics and JD.com (kaur and Chawla, 2021; Martin and Bustamante, 2021; Perambalam et al., 2021; Silva et al., 2021; Van Delden et al., 2021; Zareba et al., 2021).

1.2. Analysis of the current situation and the necessity of social investigation

China is still in a stage of rapid development due to its larger population and limited land area. It is actively developing urban

agriculture and has accumulated rich development experience and made great scientific and technological progress, which can be used as a model by other nations and even the entire world to address the food shortage crisis. This is done in order to effectively address the problem between the rapid population growth and the loss of agricultural labor force, as well as the growing shortage of land resources. The plant factory and vertical farm share many common features in design and substance, commonly known as "Plant factory" in Asia and often called "Vertical farm" in Europe and the Americas, is an intensive industrialized agricultural production system with vertically stacked or inclined shelves (Marks, 2014; Al-Kodmany, 2018; Goldstein, 2018). In fact, the two are current agricultural new technologies and systems that have been created from various academic and practical viewpoints that are both distinct and related (Harbick and Albright, 2016; Kikuchi et al., 2018), and can be seen from Figure 1. This study is not concerned with the concept, and a fine distinction is not intended. However, from the point of view of their common characteristics, both of them are new agricultural production systems integrating information electronics, automatic control, artificial intelligence, mechanical technology, botany, light quality physiology, horticulture, agronomy, and other disciplines (Chen et al., 2013; Ohara et al., 2015; Khan and Ahmed, 2017; Hu et al., 2018; Liu et al., 2019; Wang et al., 2022a). They have realized the accurate and controllable growth environment of crops, the comprehensive reorganization and optimization of resources and energy consumption, and the overall ecological friendliness of environmental contamination (Ioslovich and Gutman, 2000; Brummer et al., 2011; Beacham et al., 2019; Tuomisto, 2019). It is viewed as a methodical initiative for the sustainable development of modern agriculture in the future and is the preferred solution for raising agricultural output to alleviate the burden on food security, local famine, and urban population expansion (Nakayama, 1991; Avgoustaki and Xydis, 2020; Teo and Go, 2021). Their common advantages (Kozai, 2018; Tong et al., 2020) are: (1) the plant growth environment is accurate and controllable, which can achieve high efficiency and energy saving. (2) Plants can be produced continuously all year round, not affected by the sudden epidemic and extreme climate, which improves food safety. (3) It is independent of sunlight and does not require land. It makes the most sense to construct it in a city where it can supply the locals with fresh vegetables. (4) A location with a protracted climate and unsuitable soil for plant development is ideal for construction. (5) It provides the excellent benefit of enhancing product quality by controlling the environment for plant growth. (6) It ensures the sustainable growth of society and significantly raises the rate of land utilization. (7) Plant products can be mass-produced in the workshop on a similar basis to industrial goods. (8) Improve the environment and working circumstances for operators, draw in young professionals, etc.

At the same time, these two new modes of agricultural production have encountered many obstacles and practical difficulties (Kim, 2010; Eaves and Eaves, 2018; Xydis et al., 2020), and have been questioned and worried. The main obstacles are: (1) The price of the construction is too high. (2) Operating expenses are excessive. (3) The production technique is complex. (4) The economic gain is modest. (5) There is insufficient government assistance. (6) The product's level of quality is insufficient. (7) Product diversity alone is insufficient. (8) The level of consumer recognition is low. (9) There is no active marketing. (10) Product development is slow, etc. The primary issues and concerns are: (1) The cost is prohibitively expensive. (2) There is debate over its nutritional worth. (3) Uncertain of its healthfulness. (4) There may or may not be industrial pollution. (5) Uncertain of its cleanliness, lack of contamination, etc.

Despite the fact that academia and business view the plant factory and the vertical farm as sustainable agricultural production systems for addressing the threats posed by climate change, geological conditions, land problems, population problems, food problems, food security problems, energy problems, the aging of agricultural personnel, the environment, and sustainable development. The development of industrial manufacturing, the health sector, the information sector, and other industries can all be driven by these sectors, which are also regarded as intermediate industries for sustainable urban development. Many researchers have made in-depth research in this aspect (Glenna et al., 2011; Rajan et al., 2019). These innovative modern agricultural technologies, however, are insufficient on their own to convince growers or investors to switch to this new way of production. To entice more investment, it is more important to demonstrate their production potential market prospect and profitability through research or other evaluation techniques (Kim et al., 2013; Shao, 2013), which is easy to ignore (Huang, 2019; Yano et al., 2021). Therefore, through the method of questionnaire and interview, this study conducted an extensive social survey on the attitude, cognition, recognition, participation, willingness to pay, and brand awareness of agricultural managers, scholars, producers, sellers, and consumers toward plant factories and vertical farms. The purpose of the survey is to analyze the challenges facing science, technology, and market promotion, as well as to investigate practical solutions and effective coping mechanisms for the sustainable and healthy development of these fields. The findings of this study provide valuable guidance for formulating development strategies that are appropriate for successful marketing, recovering R&D costs through market revenue, attracting additional industrial investment and policy support, and sustaining R&D, production, and sales.

2. Materials and methods

2.1. Analysis of investigated people and their roles

Urban agriculture research has advanced, leading to the development of numerous agricultural sustainable production systems with contemporary high-tech characteristics that are progressively moving toward industrialization, commercialization, and sustainable production. To address the issues and challenges faced in practice, it is essential to conduct focused research and investigation into the social group structures that influence or participate in the growth of the plant factory and vertical farm industries from an economics perspective. Five social groups, namely government management departments, scientific research institutions, production enterprises, sales companies, and consumers, are closely related to the interests of plant

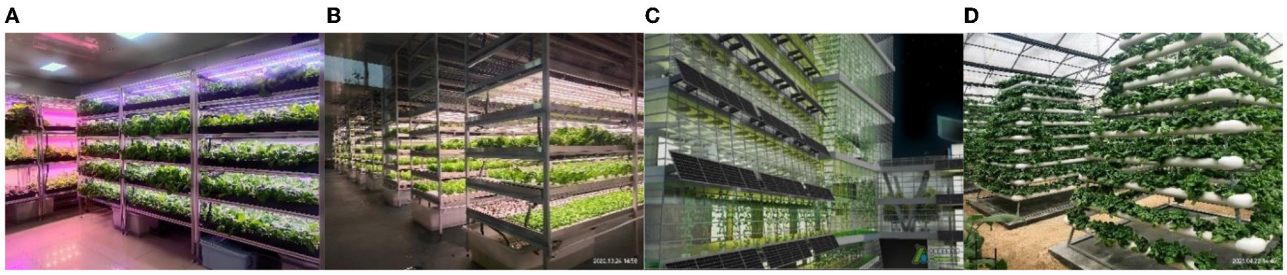

FIGURE 1
Plant Factories [**(A)** plant factory laboratory of our university, **(B)** taken in Xi'an, China] and Vertical Farms [**(C)** selected from network and **(D)** taken in Shouguang, China].

TABLE 1 The first part of the questionnaire (social-demographic characteristics survey).

Number	Question type	Question title	Question options
1	Single Choice	Your gender is:	Male OR Female
2	Single Choice	Your age is:	18–30 years old, 30–45 years old, 45–60 years old OR 60 and above
3	Single Choice	Your highest education (including current education) is:	Senior High School / Technical School and Below, Technical Secondary School / College, Undergraduate College OR Master Degree or above
4	Single Choice	Your recent resident area is:	North China, Northeast China, East China, Central China, Northwest China, Southwest China OR South China
5	Single Choice	Your industry (if not the first four, choose the fifth one):	Government Administration, Scientific Research Institutions or Universities, Agricultural Production Enterprises, Agricultural Products Marketing Company OR Consumers of Agricultural Products
6	Single Choice	Your average monthly income is:	< RMB 3000, RMB 3000-5000, RMB 5000-10000, RMB 10000, and above

factories and vertical farms, respectively. Based on this analysis, the questionnaire design and interview strategy for this study are carried out.

2.2. Sampling

To fully understand the understanding, attitude, recognition, and purchase intention of industry practitioners and different social consumers to the plant factory and vertical farm, as well as the care degree and price acceptance limit of brand products, to ensure the universality and diversity of the sample, this study adopts the multi-stage cluster sampling survey method and face-to-face interview strategy. According to the analysis in Section 2.1, the target population of this survey is the permanent population living in China. According to the sociological characteristics, the respondents are mainly targeted at the following five groups: government administrators from agricultural and rural areas or science and technology management, scientific research personnel from scientific research institutions or universities, production personnel from farm products production enterprises, sales personnel from agricultural products sales companies and consumers of agricultural products. To speed up and shorten the survey process, from the perspective of consumers, the other four groups except potential consumers are also considered as potential consumers. In this way, the survey looks into the opinions and attitudes of these particular groups toward vertical farms and plant factories. To ensure the universality, effectiveness, and timeliness of social survey, according to the situation of using communication tools to Chinese social networks and residents, the online electronic questionnaire is pushed to friends or friend groups through network and instant communication tools software to launch consumers to fill out and write questionnaires online and collect feedback questionnaires automatically through the network. In addition, the survey intends to comprehend the attitude, comprehension, and opinions of government officials, research experts, entrepreneurs, and particular customers through point-to-point voice conversations and in-person interviews, recording the interview contents, and sorting out the survey results. A face-to-face interview is the primary method used in the survey of the managers from the government's agricultural and rural areas and science and technology management departments, with a questionnaire survey serving as a backup. In addition to serving the survey's intended aim, this format offers a great chance to thoroughly comprehend national policies and interact with decision-makers. We mainly use questionnaire surveys in our surveys of academic researchers and college and university professors, with phone calls and in-person interviews serving as supplements. Researchers and agricultural production firm personnel both participate in the investigation. In the survey of potential consumers, we almost all adopt the way of the questionnaire survey, but we also conduct face-to-face interviews

TABLE 2 The second part of the questionnaire (investigation on consumers' understanding and cognitive level).

Number	Question type	Question title	Question options
7	Single Choice	Have you heard of plant factories and vertical farms before?	Yes, I've heard about it before. OR No, I never heard of it. I heard it for the first time today.
8	Single Choice Questions with Illustrations	Plant factories and vertical farm products are shown in the picture. What kinds of things have you seen?	Haven't seen any of them, Have seen 1-3, Have seen 4-6 OR Have seen more than 6
9	Grading Questions	How much do you think you know about plant factories and vertical farms and their agricultural products?	A star - never heard of before, Two stars - know little, Three stars - learn more, Four stars - learn a lot OR Five stars - very understanding
10	Multiple Choice	What do you think is the reason why you know little about plant factories and vertical farms and their crop products?	Too little media coverage, insufficient popularization of scientific and technological knowledge, too few reports on scientific research results, The scale of production is too small to popularize the market, Product marketing activities are too few to know what products come from plant factories or vertical agriculture AND other reasons

TABLE 3 The third part of the questionnaire (investigation of consumers' doubts, concerns, or obstacles).

Number	Question type	Question title	Question options
11	Multiple Choice	What do you think are the main factors that affect the development of plant factories and vertical farms?	Too high construction costs, too high operating costs, complex production technology, Insufficient government support, Not high enough product quality, Not enough product diversity, Consumer recognition, too little marketing, R&D lag, AND Other factors
12	Multiple Choice	What are your concerns about the agricultural products of plant factories and vertical farms?	The price is too high to afford. Its nutritional value cannot be determined. Not sure if it's good for your health, Uncertain whether there is industrial pollution, Uncertain whether it is clean and nuisanceless, other aspects

with as many consumers as possible, to fully understand the actual needs and real ideas of ordinary consumers, and increase the understanding and grasp of the real market.

2.3. Questionnaire design

The design of the questionnaire is crucial for this study since it serves as both the carrier and the cornerstone of the research, as well as a tool for data collection. To help the subjects fully comprehend the pertinent information, the questionnaire takes the form of an online electronic survey with text, images, and video data attached. The questionnaire consists of five parts. Each part includes two or more different questions with a total of 20 questions; all questions are required to be answered. The first section mainly inquired about the social demographic characteristics of the respondents. There are six questions, including their gender, age, education level, area of current home, industry, and monthly income level. See Table 1 for details. The second section aims to ask the subjects about their level of cognitive development and understanding of plant factories, vertical farms, and their products, as shown in Table 2. The third section aims to assess the subjects' reservations, worries, or obstacles regarding the growth of plant factories and vertical farms, as shown in Table 3. The fourth section is mainly used to understand the consumer's willingness to purchase products and price expectations, as shown in Table 4. The fifth part mainly inquires about consumers' trust, awareness, purchase anticipation, and pricing anticipation for brand-name goods, as shown in Table 5.

To ensure that the questionnaire reflects the true thoughts and wishes of the respondents, the questionnaire is anonymous and does not ask for and record sensitive information such as the respondents' names, identifying information and contact information.

According to the analysis in 2.1, the fifth item, a single-choice question, was intended to be in the first section of the questionnaire to help the researcher understand the distribution of the respondents' jobs. Only one of five choices - government officials, academic researchers, producers, sellers and consumers - was available to find out which industry the respondents came from. If a respondent does not fit into one of the first four categories, they are advised to select the fifth category, which is "consumers of agricultural products." These four groups of people are considered to be the actual consumers of agricultural products in this social study.

In this survey, we conducted a questionnaires survey and interviews with government managers, because managers are the people who have the knowledge and formulate policies, and are the macro-regulators of agricultural or scientific and technological development, research, production, sales and even consumption. The direction of development and the rate of building of plant factories and vertical farms are significantly influenced by their level of knowledge, degree of understanding, attitude, and worldview. The reason for the questionnaire survey for scientists is that they are the forerunners and think tanks of this new science and technology. They also set the pace for technological advancement across the board. Understanding the research trends can help you understand and grasp the future development direction and outlook of plant factories and vertical farms. Producers and sellers are the builders of this modern agricultural industry. Investigating and understanding their true thinking is conducive to better identifying problems from practice and improving production and

TABLE 4 The fourth part of the questionnaire (investigation on consumers' purchase intention, price expectation and primary purchase reason).

Number	Question type	Question title	Question options
13	Single Choice	If the price is right, would you like to buy the plant factory and vertical farm" products?	"Certainly," "Maybe" OR "Will not buy."
14	Single choice	Compared with traditional agricultural products, how much higher do you think the prices of agricultural products from plant factories and vertical farms are appropriate?	Slightly higher, not more than 1.50 times, More than 1.5 times but <2 times, More than 2 times but <3 times, Three to five times is acceptable OR More than 5 times, unacceptable.
15	Single choice	What is the primary reason for you to buy products from the plant factory and the vertical farm?	Clean nuisanceless, superior quality, High nutritional index, High freshness, Green health OR Other aspects.

TABLE 5 The fifth part of the questionnaire (investigation on consumers' trust, recognition, brand care, and price expectation of brand products).

Number	Question type	Question title	Question options
16	Single Choice	What do you think of the prospects for plant factories and vertical farms and their crop products?	"Must be," "Maybe" OR "Not"
17	Multiple Choice	What do you think are the advantages of plant factories and vertical farms?	The plant growth environment is accurate and controllable, which can achieve high efficiency and energy saving. Plants can be produced continuously every year to improve food safety (e.g. outbreak, extreme climate impact, etc.), It doesn't need land and sunlight. It's most suitable to be built in the city to supply fresh vegetables for the citizens, It is best for the construction of long climate and poor land areas which are not suitable for plant growth, It has great advantages of improving product quality by regulating plant growth environment, Greatly improve the land-use rate, to ensure the sustainable development of society, So that plant products can be as large-scale production in the workshop as industrial products, AND other aspects.
18	Multiple Choice	What channels do you most want to get information about plant factories and vertical farms and their crop products?	Official news media, We media or social media, Government administration, Research institutions, academic organizations of Universities, Production enterprises or agricultural technology companies, Supermarkets, chain stores or markets for agricultural products and "Other channels."
19	Single Choice	Do you care about the trademarks and brands of agricultural products?	"Very concerned," "More concerned" OR "Don't care
20	Single Choice	How much more do you think it is reasonable to charge for a branded product than a generic one?	"Slightly higher," "No more than 1.50 times, definitely choose branded products," "More than 1.5 times but less than 3 times, preferring to choose branded products," "More than 3 times but less than 5 times, will still consider buying branded products," "More than 5 times, definitely will not choose brand products".

management techniques, processes and methods. Consumers are the end users, and products that are not recognized and accepted by users cannot be developed in the long term. Therefore, it is appropriate and correct to scientifically select the target group and push the electronic questionnaire to them using random sampling in order to make the study general, effective, methodical, scientific and verifiable.

2.4. Statistical analysis method

Descriptive statistical analysis, cross analysis, variance analysis, multivariate regression analysis, and other mathematical statistical analysis methods were used in the study.

The descriptive statistical analysis method is mainly used to analyze the social demographic distribution of the subjects, to objectively understand their understanding, knowledge level, and cognitive depth of this new agricultural production mode, as well as their attitudes, opinions, concerns, recognition, purchase intention, brand care, and price expectation, and to analyze the main reasons why they are willing to buy or unwilling to buy.

Using the cross-analysis method, this paper compares and analyzes the effects of consumers' gender, age, education level, place of residence, occupation, and level of monthly income on their ability to comprehend, level of knowledge, cognitive ability, attitude, view, worry, intention to purchase, price expectation, and brand care of plant factories and vertical farms. The results of the research and analysis are of practical and scientific importance for policymaking, project research and development, industrial planning, resource regulation, production planning, sales planning and health consumption.

Using multiple regression analysis, this study examines and evaluates the impact of consumer social demographics and purchasing behavior on purchasing intentions. Social demography and purchasing behavior are common variables of market segmentation, which enables marketers to accurately identify the most suitable consumer groups and provide them with the most intimate services (Armstrong and Kotler, 2003). The findings

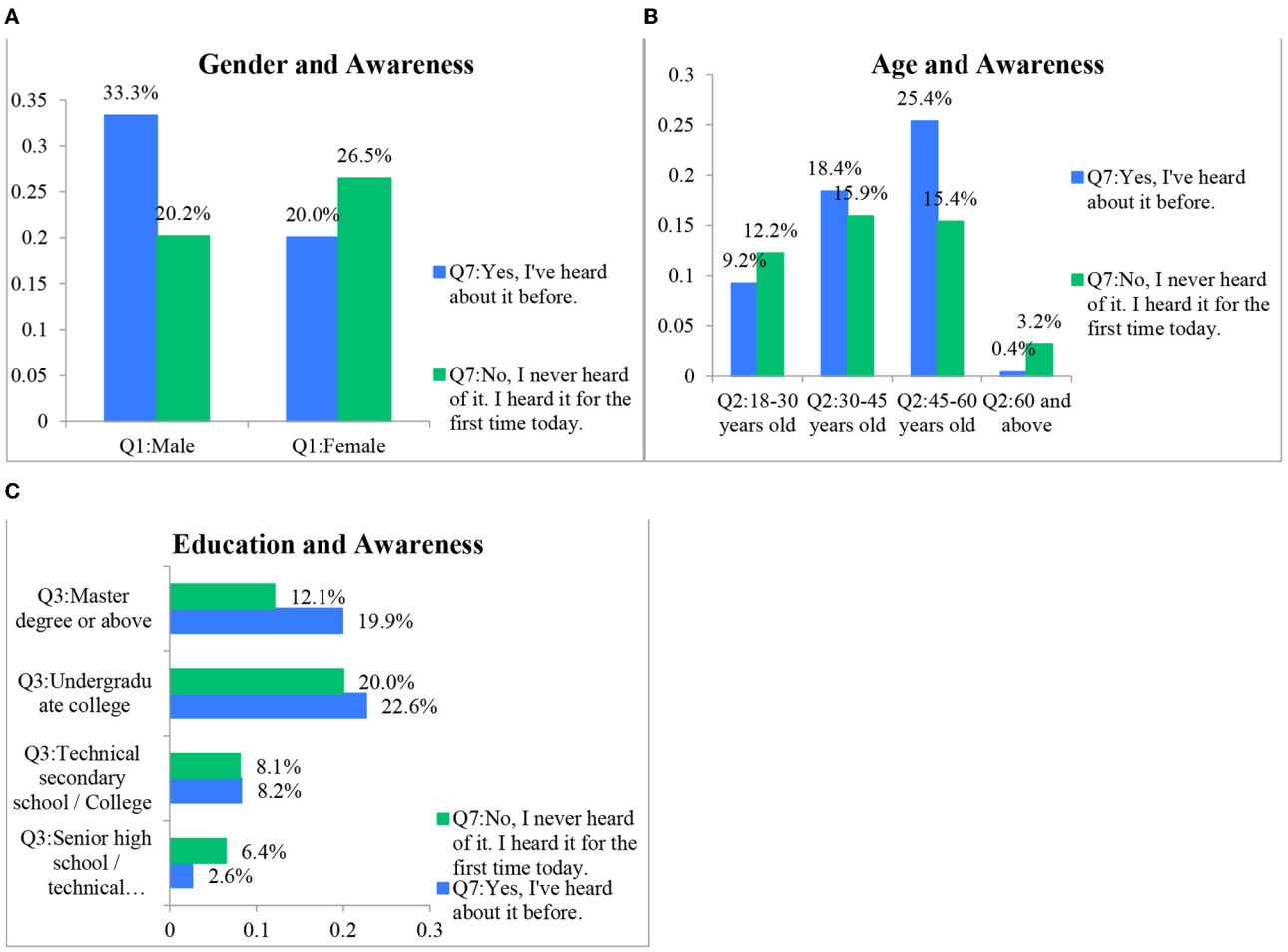

FIGURE 2
Cross analysis of different gender **(A)**, Age **(B)**, Education level **(C)** on Plant factory awareness.

of this analysis can be used by producers to pinpoint the customers most likely to purchase this novel agricultural category and to define their precise requirements. The conclusions help producers better plan construction scale, develop production plans, direct product production, upgrade technical equipment, enhance process flow, upgrade product quality, plan marketing and plan future development prospects.

3. Results and discussion

3.1. Questionnaire collection and statistical analysis

WeChat and QQ are two popular social media platforms in China with a large number of users. The electronic questionnaire, which has the universality of social investigation and research, was sent to respondents *via* WeChat, QQ and other social platforms, with a large base of respondents and random recipients. The design, testing and piloting of the questionnaire was completed in early November 2020. The questionnaire was conducted in three phases. The first phase, referred to as the primary investigation phase, lasted for more than 3 months, starting on December 6, 2020 when the electronic questionnaire was sent out, until March 6, 2021 when the final feedback from the questionnaire was collected. The second phase, a follow-up survey, will be conducted from March 7 to April 9, 2021 to make up for the lack of respondents in the first phase and to broaden the pool of respondents beyond the authors' home regions. The third phase is the voice and on-the-spot interview phase, where key members of government staff and subject matter experts are interviewed directly. More than 800 questionnaires were submitted during the three phases, of which 729 were available for statistical analysis. After extensive testing before the questionnaire was released, simply going through it from start to finish took 20 min, compared with an average response time of 38 min and 33 s for the 729 questionnaires. It can be seen that each questionnaire contains thoughtful responses from the respondents, which effectively reflect their actual cognitive level regarding the plant factory. The sample consisted of 46.5% women and 53.5% men, all of whom were adults over the age of 18 with experience consuming agricultural products. In addition, 74.63 percent of the subjects held a bachelor's degree or higher and possessed high levels of knowledge and cognitive ability. The subjects were from the Chinese mainland, and the number of people in each region was evenly distributed, with high regional representation:

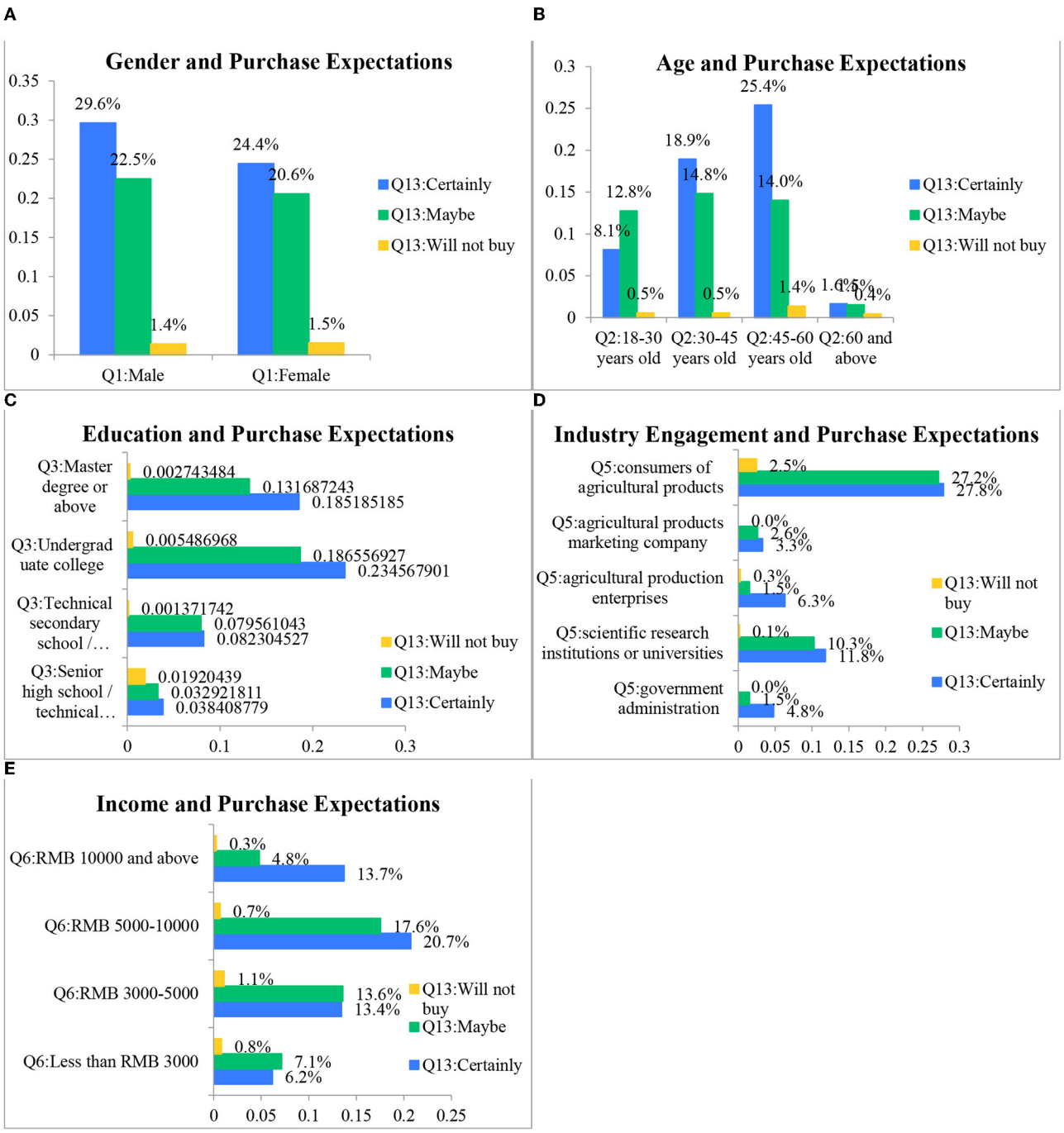

FIGURE 3
Cross analysis of different gender **(A)**, Age **(B)**, Education level **(C)**, Industry engagement **(D)** and Income **(E)** on Purchase expectations of plant factory product.

8.0% were from North China, 8.4% from Northeast China, 44.7% from East China, 8.23% from Central China, 8.37% from Northwest China, 8.6% from the Southwest, and 13.6% from the South. A total of 6.3% of respondents were from government administration, 22.2% from scientific research institutions, 8.1% from production companies, 5.9% from sales companies and 57.5% from consumers. The fact that each respondent is a consumer makes the survey representative of the industry and universal among consumers. High-income respondents accounted for 18.8%, higher-income respondents 39.0%, middle-income respondents 28.1%, and low-income respondents 14.1%. The income levels of the respondents are representative and universal.

These findings demonstrate the relevance, generality and representativeness of this sociological survey. It should be noted that since the authors are from central China and scientific research

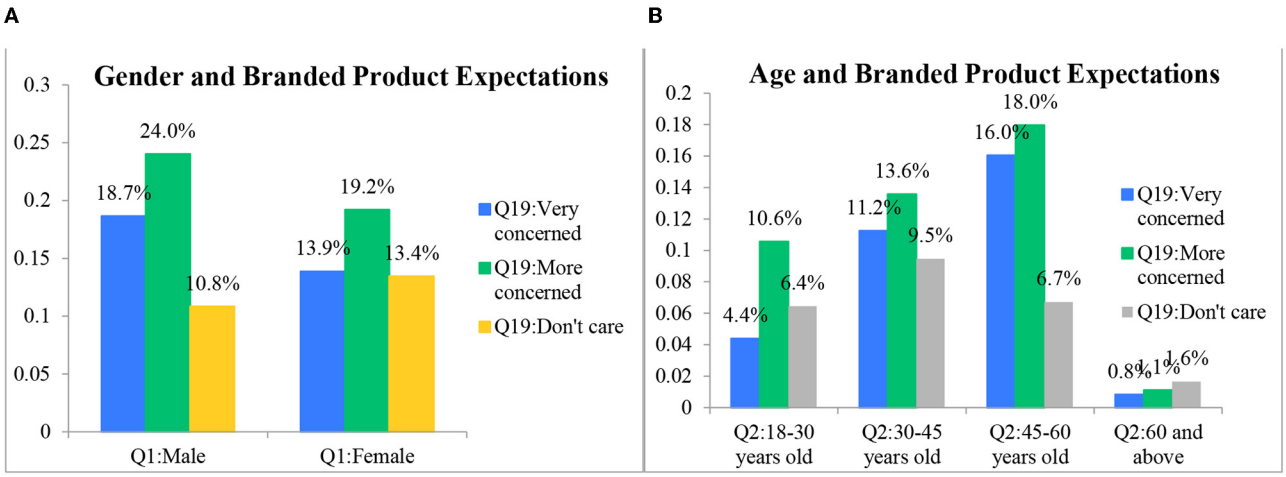

FIGURE 4
Cross analysis of different gender **(A)**, Age **(B)** on Product brand of plant factory.

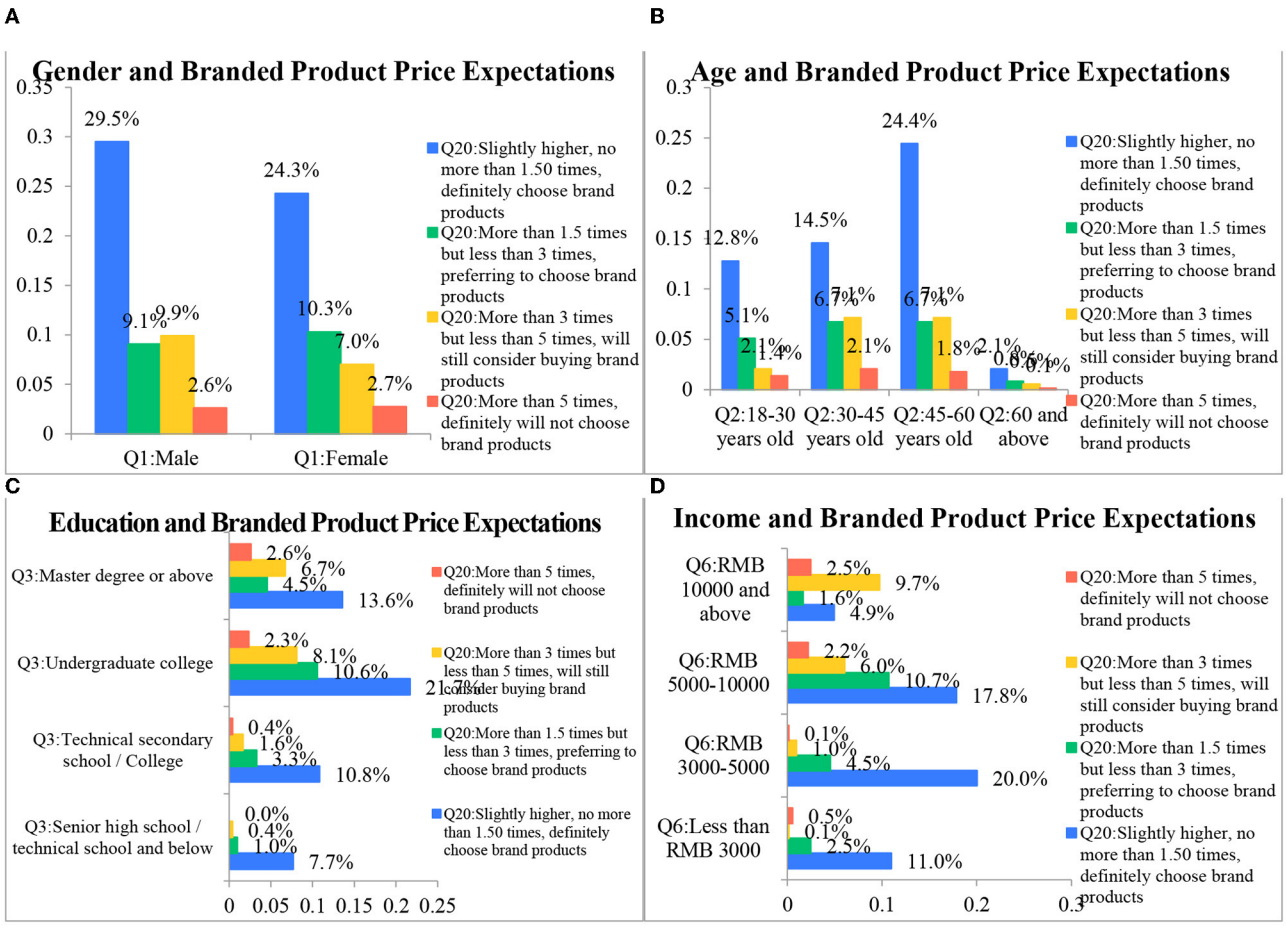

FIGURE 5
Cross analysis of different gender **(A)**, Age **(B)**, Education level **(C)**, Income **(D)** on price expectation of plant factory brand product.

institutions, there are more respondents from central China and scientific research institutions; However, this does not affect the social universality of the survey but rather confirms its universality and validity.

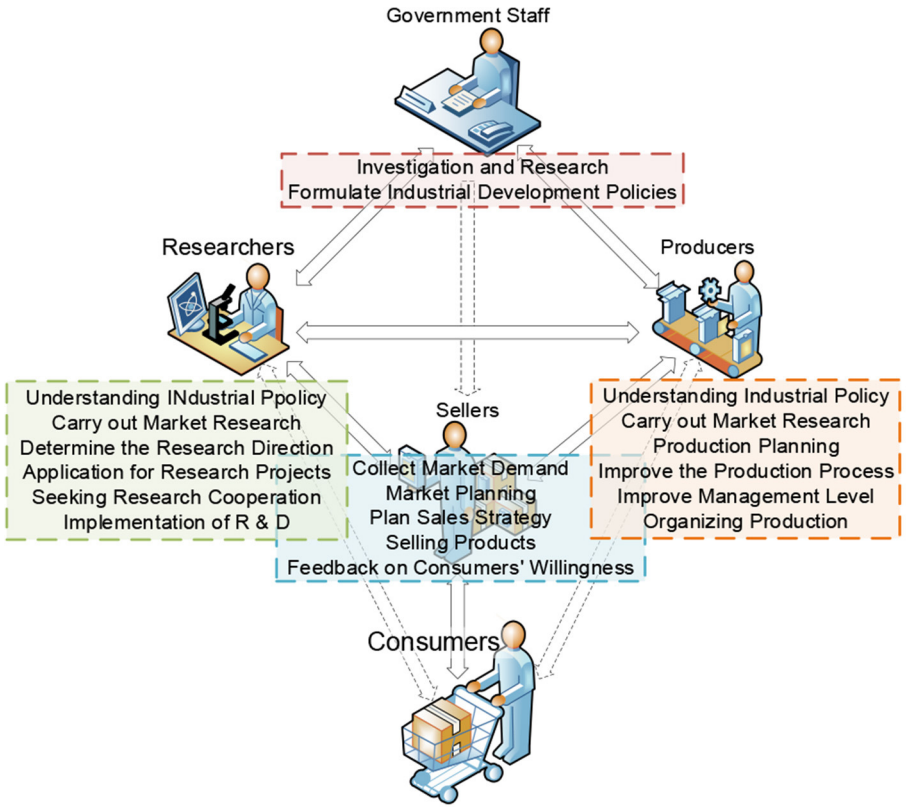

FIGURE 6
Social group role, function, and interaction model.

3.2. Results of the survey

The survey results revealed that 46.6% of customers had never heard of a plant factory or vertical farm and believed they knew nothing about them. 73.3% of respondents believed that the major factor limiting its development is the high construction cost; 66.4% of consumers believe that it is the too-high operation cost; 59.2% believe that it is the lack of consumer recognition; and 56.1% believe that there is not enough marketing promotion. 70.6% of the respondents were concerned with the high price, 59.5% with the low nutritional content, 54.7% with whether it was beneficial to health, 48.6% with industrial pollution, and 48.3% with whether it was clean and pollution-free. Nonetheless, 97.1% of respondents stated they would be interested in purchasing this type of plant product, and 54.5% said they would definitely purchase it. 93.6% of respondents are optimistic about the future of plant factories and vertical farms, and 49.4% of them are extremely optimistic. The main reason they purchase plant products from plant factories is that they are clean and pollution-free, which accounts for 39.3% of the total, followed by green and healthy (30.3%), high freshness (17.6%), high quality (8.8%), a high nutrition index (3.7%), and other reasons (0.3%). 75.7% of the subjects stated that they would be willing to buy brand name agricultural produce for everyday consumption; 32.5% of the subjects indicating that they were very concerned about the product's brand. 76.7% of respondents responded that the price of branded products should not be excessively higher than that of ordinary products, whereas 23.3% of respondents were willing to pay three times or more. The survey also found that 72.8 and 64.3% of respondents intended to learn about a product through official news media and market circulation channels, respectively.

FIGURE 7
New development mode of "Three directions and one entity."

3.3. Analysis of the survey

In China, as the government's investment and policy support for modern agriculture and smart agriculture have increased year by year in recent years, an increasing number of experimental and demonstration plant factories and vertical farms are being

built across the country, with approximately 300 such plants having been constructed by the end of 2019 across the country (Data from China Industry Research Network, Research Report on current situation analysis and development trend of plant factory industry in China from 2020 to 2026, 2020,9). The study of survey data reveals that an increasing number of consumers are beginning to comprehend and accept this new form of plant production and are willing to purchase the plant products of plant factories and vertical agriculture. They believe that plant factories and vertical farms will become one of the primary methods of urban agricultural production in the future. This energy-saving, resource-saving, and environmentally friendly sustainable system for plant production has the following advantages: (1) It can be constructed in a region with a long growing season and poor, unsuitable soil for plant growth. (2) It does not require land or sunlight. (3) It is suitable to be constructed in the city to provide residents with fresh vegetables. (4) Plants can be produced year-round to improve food safety in the event of an emergency (such as an outbreak, an extreme climate impact, etc.). (5) It significantly increases the rate of land utilization and promotes the sustainable development of society. (6) By managing the plant's growing environment, it provides many advantages for enhancing product quality. (7) Like industrial products, plant products can be produced on a large scale in the workshop. (8) The plant-growing environment is precise and under control, allowing for excellent efficiency and energy conservation. In addition, some experts noted in the expert interview that the plant factory offers extra advantages, such as increasing employment, improving the working conditions of farmers, and promoting the adjustment and optimization of the agricultural industrial structure. Some scientists have boldly predicted that in the future, more than 60% of leafy vegetable products consumed by urban dwellers will originate from urban plant factories. However, a number of obstacles are impeding the development of the plant factory, such as: (1) its enormous investment in construction and maintenance; (2) its high operating costs; (3) its complex construction technology; (4) its lack of production experience; (5) its small production scale; (6) its subpar product quality; (7) its lagging R&D; (8) its limited product diversity; (9) its weak market competitiveness; (10) its difficult market promotion; (11) its low consumer recognition; and so on. This has also led to considerable consumer concern. The price is the most concerning factor, accounting for 70.6% of the respondents, followed by nutritional value, food safety, industrial pollution, and clean and pollution-free, accounting for 59.5, 54.7, 48.6, 48.2%, etc., which indicates the direction of future work for researchers and plant-factory producers. To accelerate the commercialization of plant factories and vertical farms, it is essential to adopt new energy-saving and emission-reduction technologies to reduce production energy consumption, adopt standardized management and intensive means to improve the comprehensive utilization of resources and production efficiency, and adopt intelligent means to reduce labor costs. In short, the first job is to reduce the cost of products, followed by efforts to enhance their quality and nutritional value. In the future, the income of urban inhabitants will expand dramatically, people's lives will become increasingly affluent and refined, and the need for high-quality, clean, pollution-free, high-fresh plant products will increase. Price will no longer be the primary factor in the purchase and consumption of fresh plant products, and the purchase of big-brand and high-value-added brand products will become a trend in agricultural product consumption in the future, necessitating that the production and management of plant factories and vertical farms devote more attention to brand strategy.

3.4. Cross analysis results

By using the cross-analysis method, the relationship between gender, age, education level, occupation, income level, and cognition level of plant factory and vertical farm, purchase intention and price expectation, brand awareness, and price expectation of brand products were analyzed. The results show that: (1) In terms of understanding and acceptance of plant factory and vertical farms, as illustrated in Figure 2, male consumers are more knowledgeable and accepting of plant factories and vertical farms than female consumers (Figure 2A). Young consumers are more knowledgeable and accepting of plant factories and vertical farms than old consumers (Figure 2B). Consumers with higher education levels are more knowledgeable and accepting of plant factories and vertical farms than those with lower education levels (Figure 2C). (2) In terms of buy intent and price anticipation, as shown in Figure 3, male customers rank higher than female consumers (Figure 3A). Middle-aged consumers rank higher than young consumers, and young consumers rank higher than old consumers (Figure 3B). Consumers with higher education levels rank higher than those with lower education levels (Figure 3C). Consumers from scientific research institutions, universities, and government departments rank higher than those from manufacturing enterprises, sales companies, and ordinary consumers (Figure 3D). High-income consumers rank higher than low-income consumers (Figure 3E). (3) In terms of brand awareness and willingness to buy brand products, as shown in Figure 4, male consumers have stronger brand awareness than female consumers (Figure 4A). Middle-aged consumers have stronger brand awareness than young consumers, and young consumers have stronger brand awareness than old consumers (Figure 4B). (4) In terms of the acceptance of plant factory product prices and brand products, as shown in Figure 5, male consumers are more receptive to higher prices than female consumers (Figure 5A). The price that middle-aged consumers can accept is higher than that of young consumers, and the price that young consumers can accept is higher than that of old consumers (Figure 5B). Consumers with higher education levels can accept higher prices than those with lower education levels (Figure 5C). High-income consumers can accept higher prices than low-income consumers (Figure 5D). From the results of the analysis, we can derive the following insight: in the current planning, construction, and marketing stages of plant factories and vertical farms, we should prioritize the promotion and publicity of target groups such as male consumers, middle-aged consumers, consumers with a high level of education, and consumers with high incomes. Because these consumer groups are more likely to embrace the new high-tech

agricultural type of plant factory, to take the lead in purchasing and tasting, and to influence other customers to purchase.

4. Discussion

This social survey and research aims to understand consumers' cognitive level, development concerns, purchase expectations, brand recognition, and purchase intention of plant factory and vertical farm, a new form of modern agricultural production, through an extensive and in-depth social survey to investigate their development prospects, market potential, existing challenges, and sustainable development countermeasures and suggestions. The survey and study results suggest that 93.6% of consumers are aware that this is a new form of urban agriculture production that has the greatest future potential, can be expanded vigorously in urban areas, and is the most high-tech, eco-friendly, and resource-efficient. The majority of consumers are eager to purchase factory plant products because they are clean and pollution-free (39.3%) and green and healthy (30.3%), followed by high-tech freshness (17.6%), high quality (8.8%), and a high nutrition index (3.7%). This result is consistent with the research of You et al. and Huang (You et al., 2013; Huang, 2019). The respondents and interviewees have a better understanding of the value of plant products and the food safety of plant factories and vertical farms as a result of the social survey. In order for them to recognize that the plants grown in the plant factory may increase their taste, nutrition, and quality by precisely regulating the plant development environment factors, they will produce more innovative functional plant products to meet the health and safety requirements of various groups. It also makes them take notice that the plant factory environment is clean and sterile; the production water is strictly purified and meets the drinking standard; the components of the nutrient solution can be absorbed almost entirely by the plants and there are no residues; and the plant products produced are clean, pollution-free, and can be consumed directly without being washed.

The vast majority of consumers (97.12%) stated they would purchase plant-factory products, with 54.1% being extremely certain to purchase, 43.1% willing to purchase, and 2.9 % not purchasing. 70.6% of consumers are concerned about the price of a product, 59.5% about its nutritional content, 54.7% about bad health effects, 48.6% about industrial pollution, and 48.3% about its cleanliness and lack of pollution. The findings are consistent with surveys of consumers in Singapore and Japan (Kurihara et al., 2014). Therefore, new technology and methods should be employed in the scientific research, manufacturing, management, storage and transportation, sales, and other links of plant plants and vertical farms to maximize the complete utilization of resources and reduce operating costs (Graamans et al., 2018; Kikuchi et al., 2018), and gradually improve the comprehensive competitive advantage of products, the recognition of consumers and market occupancy rate, which is the correct choice for the sustainable and healthy development of this new agricultural production system.

Brand items are more convenient for publicity, promotion, sales, and service than non-brand products (Steenkamp, 2017), thus registering trademarks and implementing brand marketing tactics is the best approach to increase consumer recognition and market popularity. The interview, survey, and analysis of consumers' brand awareness indicate that the majority of consumers (76.7%) are more likely to trust and purchase brand products, 43.2% of respondents are more concerned about the brand, and 32.5% of respondents are extremely concerned about the brand. Furthermore, the results of the questionnaire's classification and cross-analysis demonstrate that young people, those with a high level of education, and those with a high income are more likely to accept new things, care more about product brands, and are willing to pay higher prices for brand products. Therefore, plant factory and vertical farm product marketing should focus more on these groups.

5. Conclusions, development countermeasures, and suggestions

5.1. Conclusion

Through the above comprehensive analysis, research, and in-depth discussion of the survey results, we have obtained many valuable findings, which are summarized as follows:

Although a growing number of customers have a basic understanding of the agricultural production system of plant factories and vertical farms, this comprehension is still at a fundamental level. More than half of customers have never heard of this new agricultural technique, and the level of awareness varies by demographic category. Therefore, government employees, researchers, manufacturers, and merchants must continue to collaborate to promote relevant publicity and education.

The survey finds that more than one-third of consumers have never seen one form of factory plant products, and less than one-tenth of consumers are familiar with six or more types of plant products, indicating that this type of plant products has not been introduced in large quantities to the market, and is rare in the market, with rare species and insufficient diversity, and enormous market development space and potential.

The results demonstrate that consumers tend to believe that a lack of news coverage (66.4%), marketing and promotion activities (65.7%), popularization of scientific and technological knowledge (63.8%), large-scale listing (55.1%), reports on scientific research achievements (35.9%), etc. contribute to their lack of knowledge about plant factories and vertical farms. The findings can assist producers and sellers in analyzing market development strategies.

It is found that the main factors that restrict the development of plant factories and vertical farms are high construction cost (73.3%), high operating cost (66.4%), consumer recognition (59.2%), little market promotion (56.1%), complex production technology (45.0%), insufficient government support (40.3%), low product quality (34.9%), insufficient product diversity (30.8%), and lagging R & D (19.8%), etc. Consumers were most concerned about the high price (70.6%), the questionable nutritional content (59.5%), the uncertain health advantages (54.7%), the uncertain industrial pollution (48.6%), and the uncertain cleanliness (48.3%). Clean and pollution-free (39.3%), green health (30.3%), high-tech freshness (17.6%), product quality (8.80%), and nutrition index (3.7%) were the most important purchasing considerations for consumers. These findings indicate that the main tasks of the construction and market development of this new agricultural production system are to reduce the construction and operation

costs, to study and verify the comprehensive nutritional value and safety of the products, and to ensure that the harvested products can reach consumers as quickly as possible while retaining the highest level of freshness.

The survey discovered that the vast majority of consumers (93.6%) recognize the benefits of this agricultural production system and are optimistic about its future; Many consumers (97.1%) will purchase this product in the future; and, as long as the price is reasonable or not excessively higher than that of ordinary products; 76.7% of consumers are more likely to purchase branded products. The data indicate that a brand marketing approach is the most effective method for developing this agricultural production system.

The findings of this survey have bolstered our faith in the investigation of plant factories and vertical farms, as well as our resolve to construct a contemporary agricultural production system with strict environmental regulations and high resource sustainability. It will enable us to study, plan, construct, and develop this new type of agricultural production in a scientific, reasonable, and organized manner, promote high-tech agriculture, which is related to the future sustainability and food safety of humanity, to realize scale, industrialization, commercialization, and marketization, and provide immediate benefits to cities with dense populations. It is suggested that multidisciplinary research should be carried out from the perspectives of urban development, modern architecture, commercial economy, environmental protection, and resource sustainability.

5.2. Development countermeasures and suggestions

This social survey offers us with fundamental data and market information, and serves as the foundation for scientific and systematic study on plant factories and vertical farms. On this basis, the author further analyzes the roles, social functions, and interaction models of the government, scientific research institutions, production enterprises, sales companies, and consumers from the perspective of social relations, and then studies the countermeasures for the sustainable development of plant factories and vertical farms.

Because of the complexity of technology and huge investment, plant factories and vertical farms require the guidance of national policies and financial support, the multi-group interaction of the government, scientific research institutions, production enterprises, sales companies and consumers, and even the combined efforts of the whole society. The government is the leader, policymaker, organizer, promoter, and coordinator of the development of national and social undertakings, as well as the largest owner of comprehensive resources. Any fundamental research and large projects are inseparable from the government's policy direction, project driving, financial backing, and land policy, particularly the establishment of plant factories and vertical farms in urban areas. Scientific research institutes are the pioneers of scientific research, technology development, and policy theory research, and they represent the cutting edge of academic research and the highest levels of output. Obviously, the continued efforts of scientific research institutions and university researchers are also necessary for the sustainable growth of plant factories and vertical farms. The production enterprise is the principal participant in the construction, production, and operation of plant factories and vertical farms, as well as the key force and market body in its sustainable development. The sustainable development of plant factories and vertical farms is unachievable without the active engagement of sales companies, which are essential to push production means and products to the market and maintain market circulation. The recognition and attitude of consumers are also significant. It is impossible to accomplish sustainable development if their feelings, preferences, and anticipations are ignored. Figure 6 depicts the roles, functions, and interaction models of social groups.

On the basis of investigation and analysis aimed at the collected problems, doubts, and concerns, combined with the analysis of the social group role, function, and interaction model directly related to the plant factory and vertical farm industry, some coping strategies and suggestions were presented, with the purpose of mobilizing the initiative of all parties in society and uniting to pursue the sustainable development of modern agriculture.

For a nation or country, we must first reexamine the status and role of plant factories and vertical farms in modern agriculture, the national economy, social development, and human sustainable development, and define their strategic positioning. When necessary, it should be incorporated into the national strategic development plan, the medium- and long-term development plan, the national top-level design should be strengthened, urban development and major construction projects should be coordinated, national support should be increased, and a comprehensive and flawless policy support system should be established.

Mobilize the collaboration and cooperation of diverse research institutions, academic groups, multi-disciplinary experts, and industrial production enterprises to the fullest extent, conduct extensive academic discussions, carry out comprehensive and interdisciplinary theoretical research and technical development on plant factories and vertical farms, and implement a comprehensive theoretical and technical system for the entire discipline.

We should increase the scope and intensity of government support and the participation of scientific research institutions, build demonstration projects with production enterprises as the main body, strengthen product research and development from point to area, develop more, better and low-cost equipment and facilities, expand production scale and product diversity, improve product quality, and build complete technical standards, production specifications, process standards, and product standards, improve the technology system, standard system and the quality supervision system.

We will strengthen the supporting construction of network, intelligent and information-based environment monitoring platform, growth characteristics monitoring platform, production control platform, tracing and tracing platform, marketing expresses information service platform and big data analysis platform, carry out various technical training, industrial promotion, and market development, expand the marketing channels and establish a comprehensive and perfect marketing system.

Establish professional research direction or discipline of plant factory and vertical farm, include it in the teaching syllabus

of environmental engineering, facility horticulture, and other disciplines and vocational education, cultivate a large number of professional scientific and technological talents and marketing managers, expand publicity and increase marketing efforts, improve consumers' awareness and recognition, enhance brand influence, and promote the improvement of food culture.

Explore the new development strategy of "3 Positions and 1 Entity." Wang et al. (2022b) The smart plant factory with skyscrapers is expensive, technologically advanced, and systemically complex. To expand healthily and industrialize rapidly in a market environment, an appropriate development mode is required. "3 Positions and 1 Entity" is a novel form of production, operation, and management integrating "factory production, corporate management, and brand marketing" with "modern company + intelligent skyscraper" as the business and production entity. See Figure 7. The modern corporation is the originator of production and the market, and the intelligent skyscraper is the production entity of the urban plant factory's solid foundation. Factory production, business management, and brand marketing are the three components of the plant factory that face the market, satisfy the high-quality lifestyle requirements of customers, and lead the modern smart agricultural sector. The four are interconnected and interdependent. Without modern companies to fully utilize the creativity of market players and intelligent skyscrapers to serve as the production "workshop" of plant factories, there will be no foundation for the year-round, large-scale, high-capacity, high-quality, intelligent, informational, and industrialization of plant production, making it difficult to achieve the construction goal comprehensively. Factory production, company management, and brand marketing are sharp tools for the rapid growth and development of urban plant factories, which largely guarantee the industrialization of urban agricultural production, the modernization of management, the achievement of enterprise development, and the high quality of plant products.

To integrate a plant factory into urban development and feed the large-scale urban population, we must fully mobilize the enthusiasm of government agencies, scientific research institutions, production enterprises, sales companies, and consumers, so that all parties can form a joint force, maximize their role, promote the overall joint linkage, tap the potential power, integrate superior resources, and be market-oriented. With scientific and technological innovation as the support and achievement transformation as the link, we should adhere to a plant factory and vertical farm as the development orientation of urban productive agriculture. We should use the opportunity of developing plant factories to adjust the structure of the plant industry. We should take the safety supervision of plant products as the guarantee, enrich the "vegetable basket" of urban residents, increase the market supply capacity, enhance the scientific and technological innovation of agricultural modernization, improve the quality of agricultural products of plant factories, and strengthen the brand marketing of plant products, and develop more functional plant products with high added value. We should take advantage of the opportunity presented by the development of plant factories to improve the diet nutrition and healthy diet structure of citizens, boost the contribution rate of the modern plant industry to the national economy, and comprehensively promote the sustainable development of the urban productive plant industry.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

Informed consent was obtained from all participants included in the study and a separation of personal and factual data was always guaranteed. All persons and institutions involved in the production of this manuscript are informed and familiar with the results and this publication.

Author contributions

XW: data collection, designed the study, and peer-reviewed drafts. XW, VO, VZ, ZW, and MZ: research collaborator and peer-reviewed drafts. ZW: research collaborator, data collection, and data analysis, and first draft of manuscript. VO and VZ: research collaborator. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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