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Investigation of Developing Smart Agriculture in Greenhouses of Tehran Province

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Abstract

Food production in controlled cultivation areas plays a crucial role in increasing productivity and offsetting supply shortages. Product yields, water consumption, and energy use are the main parameters determining the performance of food production in a greenhouse. Smart technology is an effective solution to improve these parameters. This study aimed to identify the components, challenges, and requirements for the development of smart agriculture in greenhouses. Our case study focused on Tehran province, which encompasses a significant portion of the total greenhouses in Iran. The statistical population consisted of 20 subject-matter experts with research or executive experience in greenhouse automation, selected purposefully. Questionnaires and semi-structured interviews were used in this study to collect data. First, we identified the variables affecting the development of smart agriculture in greenhouses by using a literature review and semi-structured interviews with experts, Then, the experts were asked to evaluate the cross-influence of the identified variables through pairwise comparison. Finally, data analysis was done using MICMAC software. The findings indicate that the identified requirements and challenges have had a significant influence on the lack of smart agriculture in greenhouses. Through network analysis of influence and dependence relationships, it was found that economic requirements and challenges, technical and infrastructural requirements and challenges, legal and regulatory requirements, and institutional requirements were the most influential variables in the development of smart agriculture in Tehran province.

Keywords: Smart agriculture development, Smart greenhouse, Smartening challenges, Smartening requirements

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Introduction

One of the biggest issues facing nations is guaranteeing food security (World Health Organization (WHO), 2022). One potential solution that has caught the interest of agricultural experts to boost the productivity of production resources is production in greenhouse conditions as a means of addressing the aforementioned issues (Watson *et al.*, 2018). Currently, the environmental parameters are controlled manually in most of Iran’s greenhouses (Hatefi, 2021). Because greenhouses must have a consistent climate, manually adjusting environmental factors leads to temperature fluctuations in greenhouses, which has an impact on greenhouse performance (Morrow, 2020; Newcombe, 2019). Understanding the elements of smartening and integrating technologies into production processes is one of the stressed ways to overcome challenges and maximize the utilization of production resources. Smart technologies include a range of innovative technologies, such as smart irrigation systems, greenhouse climate control sensors, and software, etc., that integrate advanced and smart control systems into greenhouse operations (Edwin *et al.*, 2019). The implementation of smart technologies in greenhouses offers significant benefits. It increases crop performance by creating an optimal environment for plant growth, resulting in healthier and higher-quality productions (Jamal *et al.*, 2021). In addition, it improves resource efficiency by optimizing water and energy consumption, reducing waste and costs (Tao *et al.*, 2021). Smart greenhouses also reduce labor costs by automating certain tasks that were previously done manually (Fountas *et al.*, 2020). The ability to monitor and control remotely is an additional benefit. Greenhouse operators can remotely monitor and change greenhouse conditions by using real-time data supplied over the Internet of Things (Said Mohamed *et al.*, 2021; Terence & Purushothaman, 2020).

Iran's Ministry of Agriculture intends to renovate and build 50,000 greenhouses by 2025 in order to take advantage of the potential benefits of greenhouse crops (Sharghi *et al.*, 2020). Despite the efforts made in this area, data on the cultivated area of greenhouses indicates that, by the end of 2022, only 9856 hectares of greenhouses were constructed in Iran (Statistical Center of Iran, 2023), and there are also issues with the structure and management of greenhouses (Rezaei *et al.*, 2023; Zarei, 2017). According to surveys, the majority of greenhouses currently operate using outdated production methods, leading to reduced productivity and inefficient consumption of various resources such as water and energy. A comparison of Iran's greenhouse performance metrics with those of top-producing nations, including agricultural output, water usage, and energy consumption, reveals a significant performance gap (Abbasi, 2015; Moghaddasi & Anoushe Pour, 2016; Naseri, 2019; Zarei & Momeni, 2017). For example, the performance of cucumber production in the Netherlands’ greenhouses is 800 tons per hectare (CBS, 2017) while, in Iran, it is up to 300 tons per hectare (Banaeian, 2020). Despite the advances in technology and the emergence of modern methods of irrigation (Abbasi *et al.*, 2017), greenhouses still have low efficiency in water consumption in terms of water management. The water efficiency in the production of tomatoes in Iran's greenhouses is 31.4 kg/m³, while the average water efficiency in the world's greenhouses for tomato cultivation is 43 kg/m³, and in leading countries such as the Netherlands, it is 92 kg/m³. This difference is also true for cucumber and pepper (Zarei & Momeni, 2017). The analysis of energy consumption statistics also shows that energy usage is considerably higher than the average value in other countries, for instance, Turkiye (Abbasi *et al.*, 2020). In addition, Tehran province has 2574 greenhouse units and 4123 hectares, or 28 percent, of the total cultivated area of greenhouses in Iran (Agricultural Jihad Organization of Tehran province, 2021). Despite the emphasis on the quantitative and qualitative development of greenhouses in the Iranian National Acts, the greenhouses located in Tehran province are faced with the inefficient use of production resources and the weakness of using new technologies (Hatefi, 2021). Researches reveal that developing countries frequently struggle with inadequate infrastructure to make use of these technologies, including restricted Internet and electricity access, a lack of funds to invest in infrastructure development, and a shortage of professionals to offer services (Maraveas & Bartzanas, 2021). Furthermore, utilizing these technologies presents a technical lack to integrate and connect technologies, the incompatibility of current Internet of Things networks with other protocols, the inability to handle signal interference, the incompatibility with powerful devices, and the absence of support infrastructure because of their recentness (Elijah *et al*., 2018; Maraveas & Bartzanas, 2021). Consequently, technological adoption will encounter difficulties with things like network security and the precision of agricultural data (Jamil *et al*., 2022; O'Shaughnessy *et al*., 2021). Another challenge of using smart technologies in developing countries is related to the problems of the economy of scale. The small scale of greenhouses, the lack of financial ability of farmers, their weak knowledge and skills, and their unwillingness to use technologies are the important issues in this field (de Bourgogne, 2021; O'Shaughnessy *et al*., 2021). Due to the challenges mentioned in the development of smart agriculture (DSA), some studies have expressed that smartness requires the creation of the necessary technical and infrastructure platforms for the implementation of these technologies. The most crucial technological and infrastructure requirements for implementing smart technologies are developing smart technologies inside the country, preventing the import of inefficient smart systems (Abbasi *et al*., 2020), developing agricultural automation and mechanization (Ghara Biglo & Zand, 2015), developing information and communication technology infrastructures (Lakhwani *et al*., 2019; Saiz-Rubio & Rovira-Más, 2020; Shekhar *et al*., 2017), increasing the security of databases, and using protection improvement methods (Elijah *et al*., 2018; Narwane *et al*., 2022; Quy *et al*., 2022; Sontowski *et al*., 2020). The development of smart agriculture also requires efficient regulations to support and promote investment.

Therefore, based on the literature review, it can be concluded that, firstly, measuring the level of smart agriculture necessitates the development of a composite index that encompasses various dimensions of smartening. Secondly, the smartening of agriculture encounters challenges and requirements that directly and indirectly impact the different dimensions of the smart agriculture index. Consequently, enhancing this index entails addressing the challenges while also fulfilling the requirements. This concept can be illustrated through a conceptual model, as depicted in Fig. 1.

According to Fig. 1, considering smart agriculture in greenhouses requires interconnected components and challenges. The present study was conducted with the general aim of analyzing the development of smart agriculture in greenhouses in Tehran province. To achieve this goal, the current study seeks to identify the most important variables in developing smart agriculture in greenhouses in Tehran province the network of relationships between these variables and their priority, the most important solutions for developing smart agriculture in the greenhouses of Tehran province.

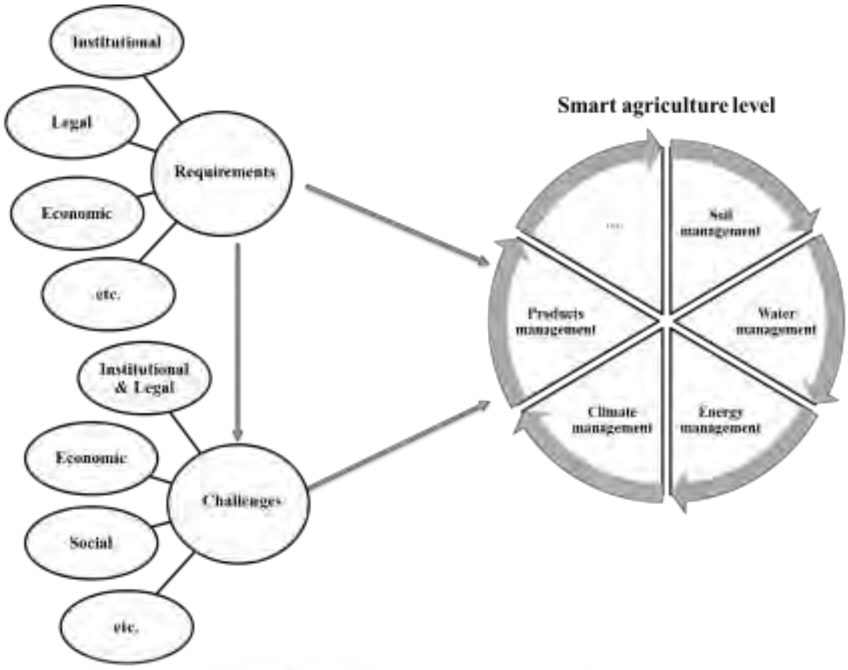

Figure 1- The conceptual model of the study

Materials and Methods

20 subject-matter experts were included in the study's statistical population. These experts included faculty members from educational and research institutions, specialists from the Ministry of Agriculture, experts from knowledge-based businesses, manufacturers of smart greenhouse equipment, and some knowledgeable greenhouse owners. Experts were selected purposefully. The data collection methods employed in this study comprised semi-structured interviews and questionnaires. Initially, through a combination of literature review and semi-structured interviews with experts, the variables influencing the development of smart agriculture, including smart components and the requirements and challenges specific to smart agriculture in greenhouses, were identified. The sample size was determined based on theoretical saturation, with each participant typically undergoing approximately 45 minutes of semi-structured interviews. Following each interview, the information gathered from participants was analyzed using the content analysis method, and the main factors were categorized according to the research's theoretical framework. To ensure the reliability of the research, a triangulation method was employed, utilizing a data pluralism strategy. This involved gathering feedback from participants, conducting self-reviews by the researcher, and meticulously documenting the interview process. Moreover, methods such as feedback from participants, self-review by the researcher, and accurate documentation of the interview process were utilized to enhance the validity of the research.In the second step, we developed a paired comparison questionnaire after identifying the key variables of the research to complete the cross-impact matrix. We asked the participants to indicate the degree of influence of each variable (x_i) on the other variable (x_j) using discrete values 1, 2, 3 and 4 which represent the no influence, weak influence, moderate influence, strong influence, , and potential influence, respectively. Finally, the information was analyzed with the MICMAC software. This software presents the distribution of factors based on their influence, dependence, and the role that they play in the system in the form of a diagram similar to Fig. 2 (Godet *et al.*, 2008). This diagram consists of five areas (Barati *et al.*, 2019):

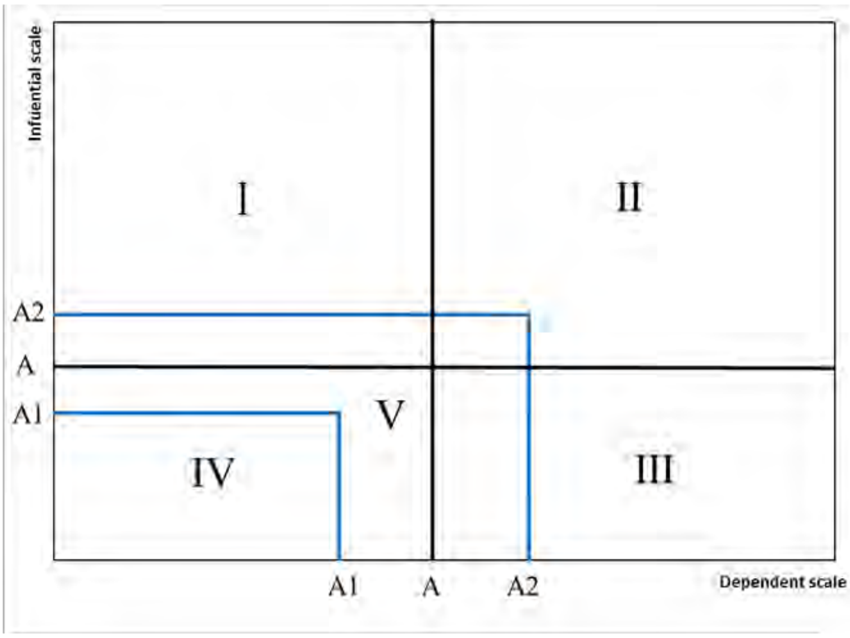

Figure 2- The influence-dependence chart area of variables

Notes: a. A refers to the average influence score (in Y axis) or dependence score (in X axis), A1= A-(0.25A), A2 = A+(0.25A)

Results and Discussion

Personal and professional characteristics of respondents

60% of the respondents had a doctorate, 30% had a master's degree, and 10% had a bachelor's degree. In terms of organizational position, 8 participants were experts in greenhouse production, 6 participants were faculty members of universities and research centers, 4 participants were greenhouse owners, and 2 participants were CEOs of knowledge-based companies. Also, 80 percent of respondents were male with an average age of 44 years, and

Identifying the effective variables for the DSA

After coding and conceptual refinement of the data obtained from semi-structured interviews, the requirements (Table 1), challenges (Table 2), and components (Table 3) of the DSA in the greenhouses of Tehran province were identified and categorized in the form of three main categories and 16 subcategories.

Out of a total of 256 evaluated relationships, the existence of 114 relationships was confirmed, and weak relationships (60 cases) and moderate relationships (35 cases) were the most frequent, respectively. The degree of matrix filling was 44.5%, and the number of iterations of the matrix to achieve optimality was 6 iterations.

Identifying the network of relationships between the variables of the DSA in greenhouses

Table 4 shows the amount and degree of direct and indirect influence of research variables on each other. Based on the results, among the requirements for the DSA in greenhouses, the economic requirements variable was ranked first with 31 scores in the direct influence, which indicates the significant importance of economic requirements in the development of smart greenhouses in Tehran province. After that, technical and infrastructural requirements, legal and regulatory requirements, institutional requirements, and learning and psychological requirements were placed in the next ranks of direct influence on the DSA. In the challenges of developing smart agriculture, economic challenges are the priority, followed by infrastructural and technical, social, and legal regulatory challenges in the next ranks of direct influence. The components of greenhouse smartening (including water management, energy, climate, products, and soil) have been the most dependent variables. The lowest level of direct influence also belonged to the variables of legal and regulatory requirements and institutional and legal challenges, respectively. In the indirect influence classification, the institutional and economic requirements and then the economic challenges are the most influential variables, and the most dependent variables are the same as in the direct influence section, respectively, the variables of the components of products management, energy, and soil.

The results of the matrix of direct and indirect influences (Fig. 3 and 4) confirm the accuracy of the research conceptual model (Fig. 1).

Table 1- Prerequisites for the development of smart agriculture in greenhouses

Subcategories	Indicators
Institutional Requirements	Development of the institution in charge of national policy and planning Development of companies providing technical-engineering services and... Improving the role of the Ministry of Agriculture-Jihad Attracting the participation of the private sector Using the capacity of greenhouse cooperatives Improving the role of universities Development of innovation centers, growth centers, and science and technology parks Creating an assembly of smart small-scale greenhouses Encouraging networking among active greenhouse producers
Legal and Regulatory Requirements	Compilation of codified policies for smart greenhouses in the country Compilation of legal incentives in the field of greenhouse smartening Compilation of rules and instructions about the Internet of Things Compilation of rules and instructions regarding obtaining a license Compilation of programs for the development of smart greenhouses Compilation of rules related to the insurance of smartening equipment
Economic Requirements	Reducing the interest rate of banking facilities related to smartening Encouraging and supporting investment in the development of IT infrastructure Financial support for start-ups and new knowledge-based companies Supporting venture capital for smartening Providing appropriate financial incentives (tariffs and taxes). Providing product and equipment insurance services in smart greenhouses
learning and Psychological Requirements	Improving producers' trust in active organizations Improving the risk tolerance of producers in adopting technologies Increasing familiarity, interest, and knowledge of producers with the process of greenhouse smartening Training of the research team and skilled human resources for service provision Content production and publication of specialized scientific publications Facilitating communication with experts and technical advisors in the smart greenhouse
Technical and Infrastructure Requirements	Facilitating access to the physical infrastructure of IT technologies Facilitating access to monitoring devices Facilitating access to smart ventilation, smart lighting, cooling, and heating equipment Facilitating access to smart irrigation and fertilizing equipment Facilitating access to data security, safety, and protection equipment Development of local, cheap, and suitable smart technologies Facilitating the import of suitable technologies according to the rate of return on capital Optimizing and facilitating the process of using data Using International experiences in smart greenhouse management Development of data storage systems

Source: Research findings

Table 2- Challenges to the development of smart agriculture in greenhouse farming

Subcategories	Indicators
Infrastructural and Technical Challenges	Poor IT infrastructure and a lack of reliable access to high-speed internet The small scale of most greenhouses Non-local and expensive greenhouse technologies lack of integrity and incompatibility of technologies Limited capacity of existing technologies in data storage Installation, maintenance, and support problems of greenhouse technologies due to technical complexity The lack of knowledge of the senior managers of the agricultural sector about smartening Importing inefficient and low-quality smart systems
Institutional and Legal Challenges	Lack of suitable institutions to provide smartening services The existence of many bureaucracies for active agricultural start-ups Violation of intellectual property of agricultural startups Violation of industrial property rights of smart technologies The uncertainty of data privacy and security in this field Lack of transparency in the duties and missions of various government and private institutions Lack of consideration of research units for the smartening of greenhouses
Economic Challenges	High cost of smart equipment and technologies Lack of appropriate and sufficient investment in the necessary infrastructure Lack of financial support and sufficient bank facilities
Social Challenges	Insufficient training in the field of smart greenhouses Lack of young manpower and the old age of producers Lack of technicians and skilled labor to provide smart technology services Lack of consideration of mass media, publications, and websites

Source: Research findings

Table 3- Components of the development of smart agriculture in greenhouse farming

Subcategories	Indicators
Water Management	Water temperature, EC and PH sensors, rainwater storage, disinfection, water recycling devices, etc.
Soil Management	Temperature, humidity, PH, and soil salinity sensor, soil disinfectant, etc.
Energy Management	Inside and outside light sensors, heating, shade, energy saving, etc.
Climate Management	Environment temperature and humidity sensors, carbon dioxide and carbon monoxide gas sensors, outside sensors, ceiling vents, exhaust fans, fans and pads, cooling systems, etc.
Products and Pest Management	Leaf temperature sensor, pest management method, LEDs, etc.
Harvesting and Packing Management	Harvesting technologies and equipment, etc.
Marketing Management	Information storage and analysis software, information and communication technologies, greenhouse marketing management software, etc.

Source: Research findings

According to them, out of the three categories of studied variables (components, requirements, and challenges of smartening in greenhouses), the requirements and challenges are the most influential, and the components of smartening are the most dependent variables, respectively (Fig. 3 and 4).

Also, according to Fig. 3 and 5, among the requirements, economic and technical infrastructure requirements are the most influential. Economic requirements directly influence different components of smartening, including water, soil, climate, and energy management. They also directly influence various challenges, including economic and technical infrastructure challenges. According to Fig. 5, the institutional requirements, both directly through the economic requirements and indirectly (Fig. 6) through influencing the components of energy management, products, soil, and climate, influence the smartening of agriculture.

Table 4- Ranking and amount of direct and indirect influence of variables

Variables	Direct influence				Indirect influence			
	Influence		dependence		Influence		dependence	
	Score	Rank	Score	Rank	Score	Rank	Score	Rank
Institutional requirements	18	5	6	11	5445649	1	166333	14
Legal and regulatory requirements	19	3	3	16	3191183	4	75161	16
Economic requirements	31	1	7	10	5059947	2	306319	10
Learning and psychological requirements	10	7	8	9	921869	9	367847	9
Technical and infrastructure requirements	22	2	6	12	1411364	8	284723	12
Infrastructure and technical challenges	15	6	5	14	1714100	6	260064	13
Institutional and legal challenges	7	10	5	15	2776753	5	97679	15
Economic challenges	19	4	6	13	3464505	3	306030	11
Social challenges	10	7	9	8	1630771	7	403356	8
Water management	10	9	19	5	222996	10	3227594	5
Soil management	2	15	21	3	62960	14	4003224	3
Climate management	7	11	20	4	196818	11	3697995	4
Energy Management	6	12	22	2	180446	12	4437860	2
Products management	6	13	23	1	117765	13	4568002	1
Harvesting and packing management	2	16	16	6	45234	16	2479680	6
Marketing Management	3	14	11	7	51436	15	1811929	7

Source: Research findings

Among the challenges, economic challenges are the most effective, both directly and indirectly. After those, there are technical and infrastructural challenges that directly affect other variables (Fig. 3). Of course, institutional and legal challenges should not be ignored because they also indirectly (Fig. 4) influence the whole system. Solving and managing challenges will directly create the background for the provision of institutional requirements (Fig. 5) and indirectly (Fig. 6) lead to the improvement of various components of smartening. Among the components of smart agriculture, the components of products, energy, and soil management are the most dependent, either directly or indirectly.

In general and based on the location of variables, economic, technical and infrastructural, institutional, and finally legal and regulatory requirements, as well as the economic and technical infrastructural challenges due to being located in the Ⅰ area (Fig. 3) are considered key factors in developing strategic plans for developing smart agriculture in greenhouses. Furthermore, the placement of water, soil, energy, climate, and harvesting and packaging management in the Ⅲ area (resultant area) means that they depend on input and intermediate variables (requirements and challenges), which is a confirmation of the conceptual model presented in Fig. 1. The performance of these variables, which are known as the components of smartening in greenhouses, mainly depends on the variables located in Ⅰ and Ⅱ areas. The variables of institutional and legal challenges are also in the Ⅳ area, which can be ignored due to the small relationship with other variables. The Ⅴ section contained the variables of social challenges, learning and psychological requirements, and marketing management. Although this group of variables is not considered crucial due to their low influence and dependence, they should be investigated in future studies.

Fig. 5 shows the intensity, direction of influence, and dependence of key variables in the development of smart greenhouses. Considering the network of direct relationships between variables, economic, technical, and infrastructure requirements have a central and sensitive role and deserve attention. Moreover, economic, technical infrastructural, and legal-regulatory requirements are the sources of the most severe influences on other system variables, which indicates their importance in developing smart agriculture in greenhouses.

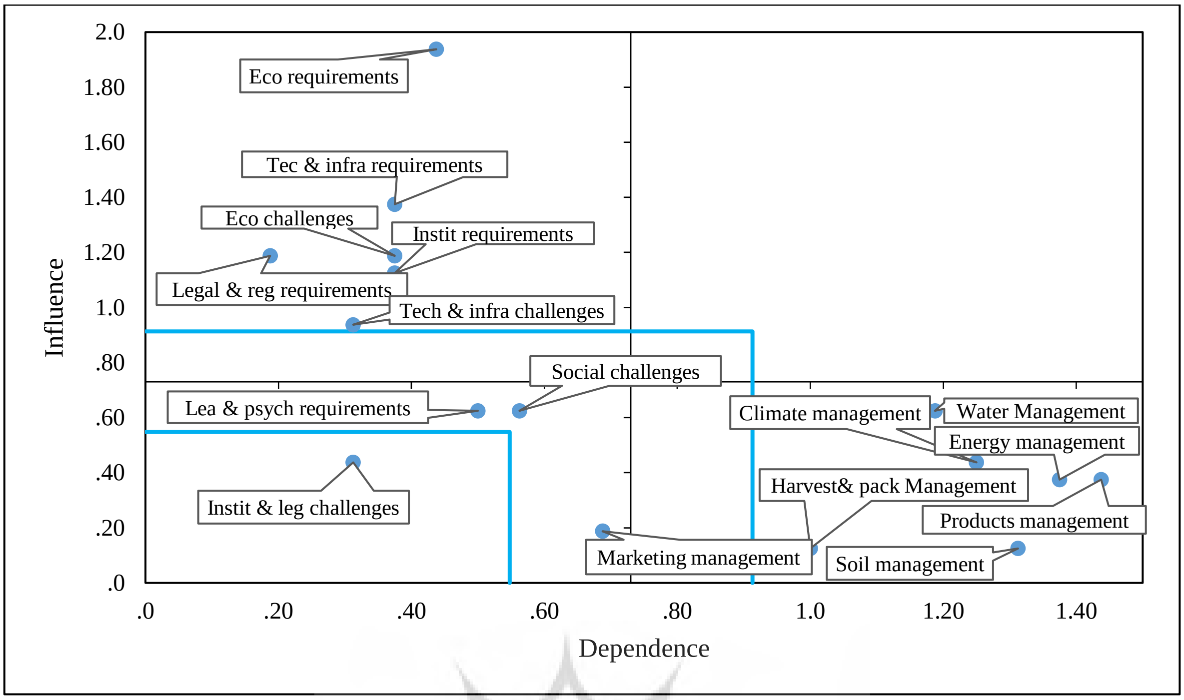

Figure 3- The position of study variables on the influence-dependence chart in the direct influence matrix

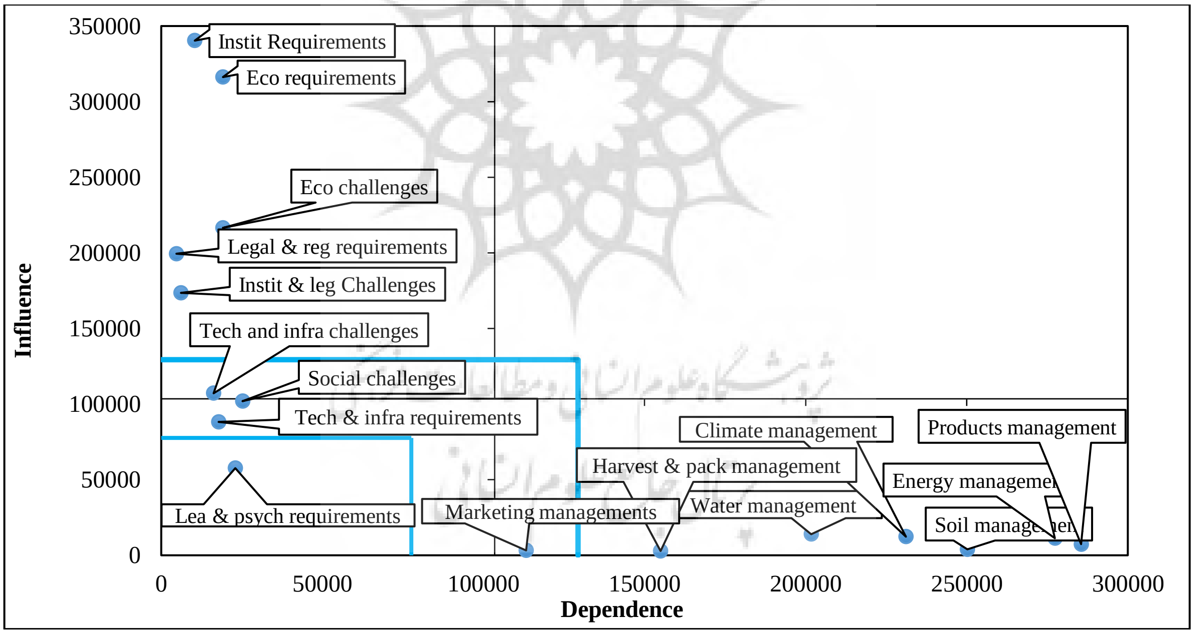

Figure 4- The position of study variables on the influence-dependence chart in the indirect influence matrix

In other ways, the components of smartening in greenhouses are strongly dependent on other system variables. In other words, improving each of the smartening components in greenhouses requires meeting the requirements and solving the challenges found in the current study. The indirect relationships graph (Fig. 6) indicates that the biggest indirect influence on other variables is derived from institutional and economic requirements.

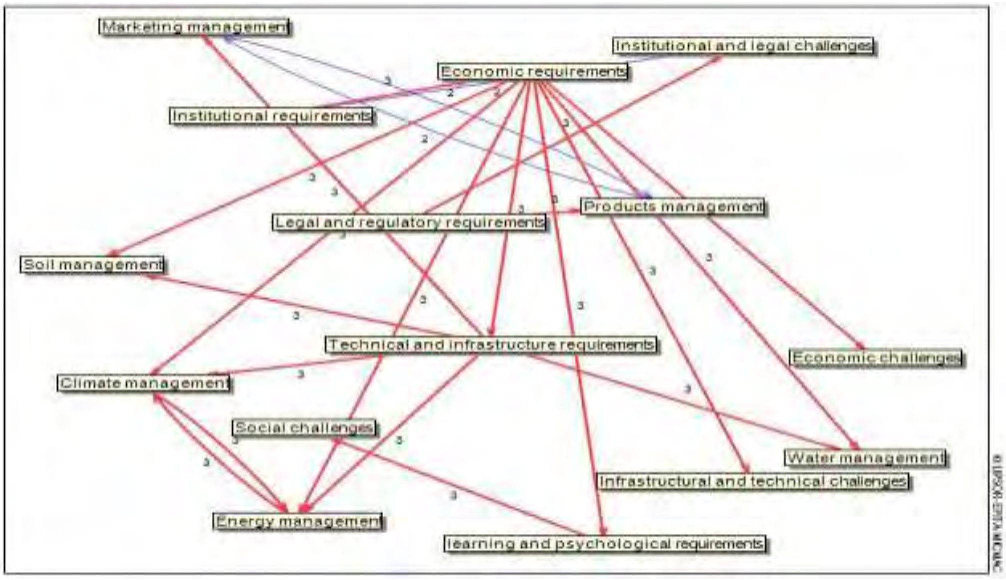

Figure 5- The graph of direct relationships between the study variables at the 25% level

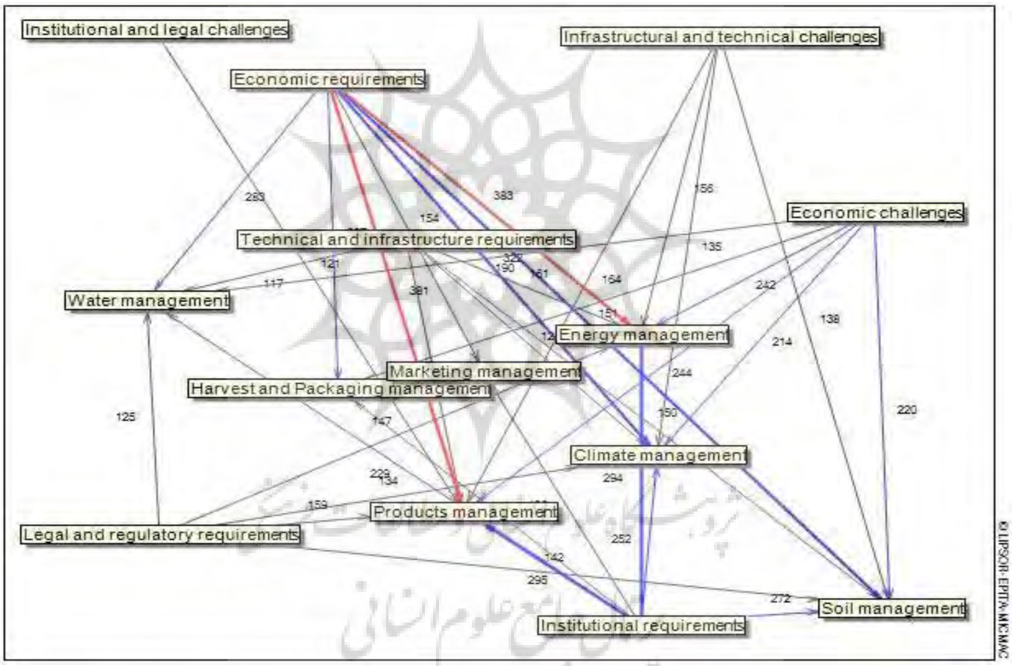

Figure 6- The graph of indirect relationships between the study variables at the 25% level

Finally, as shown in Fig. 3 to 6, the smartening components depend on the challenges and requirements identified in the development of smart greenhouses. The achievement of the goals of smart greenhouses requires intervention to overcome challenges and meet the requirements identified in this study, according to Fig. 7. In this figure, the numbers on the arrows show the general relationships of the variables based on the sum of the calculated levels.

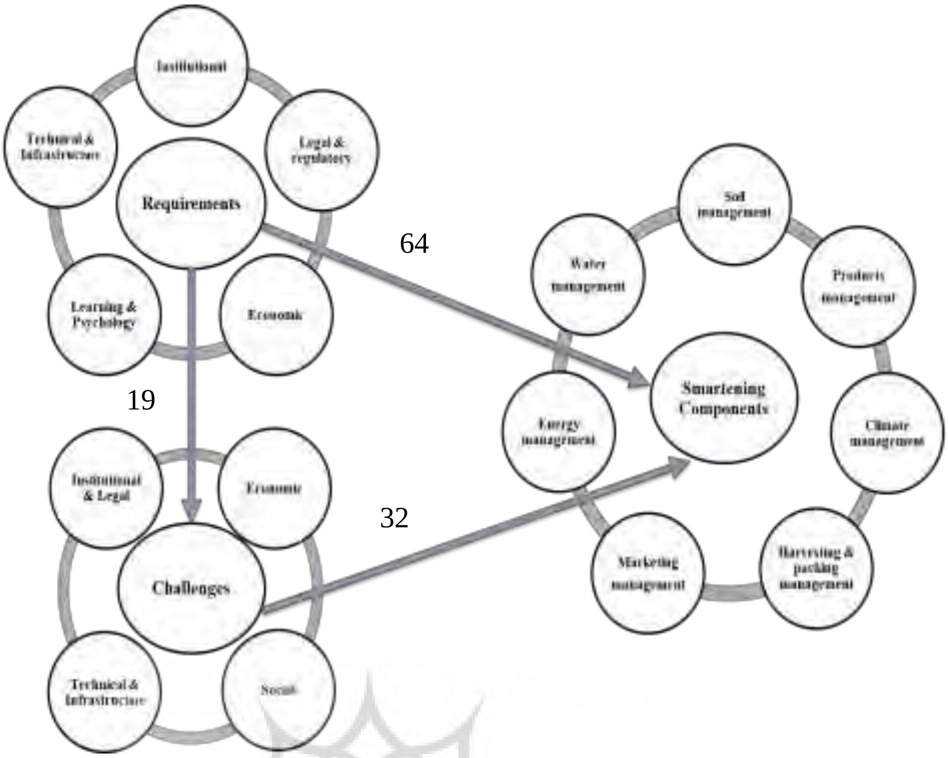

Figure 7- Final model of the study

Discussion

Developing smart agriculture in greenhouses requires addressing three categories of key factors, including requirements, challenges, and components. Predominantly, the results of this study showed that developing smart greenhouses primarily requires the provision of the requirements. Providing requirements is the direct basis for the development of smart greenhouses and helps to improve the level of smartness of greenhouses by overcoming the challenges of developing smart agriculture.

Understanding technologies and their application domains is the initial phase in their development. This study identified seven components to represent the smart technologies employed in greenhouses: water, soil, climate, energy, products, harvesting and packaging, and marketing management. Among these components, three were identified as particularly critical for greenhouse smartening: water, climate, and energy management. Investing in technologies associated with water, climate, and energy management in greenhouses not only enhances the smartness level but also establishes a foundational platform for the implementation of other smart components in greenhouses.

Therefore, the main efforts and planning for developing smart technologies in greenhouses should primarily focus on the establishment of technologies related to the three key components of water, climate, and energy management. Challenges in the field of developing smart technologies in greenhouses have influenced the success rate of using technologies in greenhouses. The network of relationships between challenges and components of smart greenhouses showed that economic, infrastructural, and technical challenges are the most important challenges influencing the development of smart greenhouses. One of the important economic challenges faced by the target community is the insufficient investment needed to develop the necessary infrastructure to make use of technologies. Studies have pointed out the shortcomings of infrastructure investment (Maraveas & Bartzanas, 2021). Given that most rural areas lack the energy, information, and communication technology infrastructures needed for smart technologies, promoting and supporting investment in developing these infrastructures can help establish the platforms needed for the expansion of smart agriculture in greenhouses. Furthermore, there is another economic challenge to the implementation of smart technologies in greenhouses: the high cost of investment, which only justifies the application of these technologies to large-scale production. Many farmers are unable to invest in technologies because of their limited financial resources and the low scale of the majority of greenhouses in the research area. Also, the lack of credit facilities to fully cover the costs of using technologies and the challenges associated with obtaining facilities are major barriers for investors and farmers looking to integrate smart technologies into their greenhouses.

Another challenge was the infrastructural and technical factors. The technical and infrastructural challenges of developing smart greenhouses can be divided into two categories: barriers related to the infrastructure as well as limitations related to farmers' access to the technologies and equipment. Many farmers will not be able to adopt greenhouse technologies even if they would like to because of barriers like weak infrastructure for information and communication technology, the small size of most greenhouses, and issues with installation, upkeep, and support. Prior research has also highlighted inadequate access to infrastructure as a barrier to the advancement of smart agriculture (de Bourgogne, 2021; Dhanaraju *et al.*, 2022). The technical shortcomings of current technologies and their incompatibility with existing agricultural operations are other limitations that have influenced developing technologies. A major part of these challenges can be attributed to the weakness of related research and the import of low-quality smart systems to the country (Abbasi *et al.*, 2020).

Considering the challenges mentioned, part of the efforts of policymakers and planners must be focused on improving the access of farmers to the basic infrastructure and the technical standards of these technologies. Based on the network of relationships between the variables of developing smart greenhouses, addressing the economic, technical, and infrastructural requirements by influencing the economic, infrastructural, and technical challenges of the development of smart greenhouses plays a central role in improving the smartness of greenhouses in Tehran province.

The results of this study are consistent with previous research (Caffaro & Cavallo, 2020; Mukhopadhyay & Suryadevara, 2014; Rayhana *et al.*, 2020), which emphasizes the importance of addressing economic issues in the process of developing smart technologies in the agricultural sector. As mentioned earlier, developing smart greenhouses in Tehran province faces important economic and technical challenges, including poor access to smart technologies and infrastructure, high investment costs, and limited access to capital. One of the strategies to overcome these challenges is to provide economic requirements through policies such as encouraging and supporting investment in information and communication technology infrastructures, investing and supporting innovations, and providing appropriate credit and insurance facilities. Therefore, farmers' incentives to invest in smart technologies can be strengthened by providing economic requirements along with a supportive economic environment.

Legal and regulatory requirements were another factor influencing the DSA in greenhouses. From the expert's point of view, legal and regulatory requirements include various aspects such as user privacy, laws related to the payment of incentives, the development of programs aimed at promoting and facilitating the adoption of these technologies, licensing procedures, and insurance laws for smart facilities and equipment. The above finding shows that developing smart technologies in greenhouses requires the development of codified rules and policies to facilitate the business environment and manage the interactions of farmers, producers, and other stakeholders involved in the smart agriculture industry. The necessity of developing appropriate laws and regulations to arrange the interactions of activists has also been considered in other studies (Atri, 2018; Narwane *et al*., 2022; Ojha *et al*., 2021). For instance, protecting farmers' information security is one of the top concerns for users of smart technology, as highlighted by numerous studies.(Elijah *et al*., 2018; Quy *et al*., 2022; Sontowski *et al*., 2020). Therefore, it is necessary to pass detailed laws and regulations that can protect the privacy of users. This issue should be prioritized in the plans of relevant politicians. Laws and regulations can facilitate the development and adoption of smart technologies by creating a favorable business environment. For example, investment in infrastructure, comprehensive development of insurance for smart facilities and equipment, allocation of financial resources to research, and payment of incentives and credit facilities to farmers for technology adoption require the passing of laws and regulations to support these policies. This means that the success of other support efforts and programs for the DSA in greenhouses, including providing economic, technical, and infrastructure requirements, requires the passing of appropriate laws and policies to support these programs.

Another important requirement influencing the development of smart greenhouses was institutional. Institutions create a supportive environment for the implementation of smart agriculture projects by formulating appropriate policies, regulations, and guidelines. This confirms the importance of institutions in fulfilling other requirements of smart agriculture development and overcoming the challenges facing this sector. The DSA primarily requires appropriate laws and policies, such as investment in infrastructure, allocation of incentives and credit facilities, research budgets, ensuring privacy and data security, etc., to coordinate efforts and implement relevant programs. The relevant institutions are in charge of making these policies. Additionally, the development of smart technologies in greenhouses requires institutions such as universities, research centers, and innovation centers. They play a fundamental role in conducting research related to smart greenhouses and help to continuously improve the development of technology in this sector. Considering the importance of technical and infrastructural requirements and challenges, technology development by these institutions provides the basis for the realization of technical and infrastructural requirements and overcoming the related challenges in the study area. For example, the Ministry of Agriculture, as a provider of information and training needed by farmers, facilitates the decision-making process regarding the adoption of smart technologies offered to farmers by providing educational-extensional programs and other interventions. In fact, by formulating laws and regulations, conducting research and development of technology, and building capacity among farmers, institutions can help create a suitable environment for the deployment of smart technologies in greenhouses.

Conclusion

In recent years, using the capabilities of smart technologies in greenhouses has attracted the attention of policymakers and agricultural planners. To effectively prioritize efforts and allocate resources for the development of smart technologies in greenhouses, understanding the factors influencing greenhouse smartness is paramount. The current study aimed to investigate the Development of smart agriculture (DSA) in greenhouses within Tehran Province. Three categories of key variables were identified and analyzed: components, challenges, and requirements. The components of smartening were classified into seven groups. Water management, climate management, and energy management components were identified as the most important components of smart greenhouses. Considering the importance of the mentioned components in the efficiency of production operations, addressing the challenges and requirements influencing these components has a vital role in the successful deployment of smart technologies in greenhouses. The analysis of the relationships between research variables showed that the implementation of smart technologies in the greenhouses of

Tehran province primarily requires the creation of a favorable economic environment by providing economic requirements, including the payment of financial incentives, credit facilities, and investment in the foundation infrastructure. Another effective factor in the development of smart greenhouses is addressing technical and infrastructural requirements and challenges. Due to the weakness of the infrastructure for the implementation of smart technologies in the country, as well as the lack of access to suitable equipment and technologies, it is necessary to take the necessary actions to overcome the mentioned challenges. Legal and institutional requirements were identified as other important factors influencing the DSA in greenhouses. As discussed, any action for overcoming the economic challenges and infrastructural and technical problems to achieve smart greenhouses requires the creation of institutions and strong legal and regulatory frameworks to coordinate efforts and support policies for the DSA in greenhouses. Therefore, to realize smart greenhouses while passing appropriate supporting laws and regulations to regulate the relations of actors, it is necessary to determine the duties of the responsible institutions in the priority of the programs of the Ministry of Agriculture and other related institutions.

Finally, according to the mentioned results, the following suggestions are presented to promote the DSA in greenhouses:

Considering economic challenges, the payment of financial incentives and special credit facilities with appropriate interest rates can increase the motivation of farmers to adopt these technologies. Moreover, regarding the importance of innovations, startups, and new knowledge-based companies in the field of smart agriculture, supporting research activities and allocating financial resources to invest in innovative ideas related to smart agriculture can create a favorable environment for the growth of related businesses.

Considering the pivotal role of information and communication technology (ICT) infrastructures in enhancing the intelligence of greenhouses, it is recommended that responsible institutions extensively provide the necessary platforms for implementing smart systems in greenhouses by investing in ICT infrastructures. The development of reliable and cost-effective internet connections in rural areas to facilitate data exchange and communication is one of the most important actions to be taken in this field.

Due to the importance of access to infrastructure and technical equipment, it is necessary to invest and make necessary arrangements for the development of supporting infrastructure and technologies required for smart greenhouses, such as smart equipment, advanced sensors, automation systems, etc. Investing in research and development to produce new technologies suited to the needs of the country's greenhouses is one of the solutions that can improve farmers' access to the necessary and cost-effective equipment and technologies in smart greenhouses.

Owing to the significant importance of institutional requirements, it is suggested that the national program for smart greenhouses in the country be formulated as soon as possible and the detailed duties of the institutions responsible for the DSA in this field be determined.

Paying attention to the role of laws and regulations in providing a suitable environment for the activities of stakeholders, it is necessary to create codified policies that outline clear guidelines and standards for farmers, producers, and other stakeholders involved in smart agriculture. These policies should cover various aspects, including implementation guidelines, incentives, user privacy, licensing procedures, and smart equipment insurance rules.

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تحلیل توسعه کشاورزی هوشمند در گلخانه‌های استان تهران

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چکیده

در دهه‌های اخیر کشت در محیط‌های گلخانه‌ای به‌عنوان یکی از راه‌حل‌های بالقوه جهت افزایش بهره‌وری منابع تولید و پاسخگویی به تقاضای غذایی فزاینده ناشی از رشد جمعیت مورد توجه کشورها قرار گرفته است. بااین‌حال، شکاف عملکردی قابل‌توجهی از نظر شاخص‌های عملکردی گلخانه‌ها نظیر عملکرد محصول، مصرف آب، انرژی و غیره در کشور ایران با کشورهای پیشرو در صنعت تولیدات گلخانه‌ای وجود دارد. یکی از راهکارهای مورد تأکید برای غلبه بر این چالش‌ها و بهینه‌سازی استفاده از منابع تولید، پیاده‌سازی فناوری‌های هوشمند در گلخانه‌ها است. با توجه به عدم توسعه فراگیر فناوری های هوشمند در گلخانه‌های استان تهران و اهمیت این استان در تولید محصولات گلخانه‌ای در کشور، مطالعه حاضر با هدف تحلیل توسعه کشاورزی هوشمند در گلخانه‌های استان تهران انجام گرفت. جامعه آماری پژوهش شامل ۲۰ نفر از خبرگان موضوعی دارای سابقه تحقیقاتی یا اجرایی در زمینه هوشمندسازی گلخانه‌ها بودند. انتخاب این افراد نیز به روش هدفمند انجام شد. ابزار جمع‌آوری داده‌ها در این پژوهش مصاحبه نیمه ساختاریافته و پرسشنامه بود. در ابتدا با استفاده از مرور ادبیات موضوع و مصاحبه‌های نیمه ساختارمند با خبرگان موضوعی، متغیرهای عوامل مؤثر بر توسعه کشاورزی هوشمند در گلخانه‌ها (شامل مؤلفه‌ها، الزامات و چالش‌های توسعه کشاورزی هوشمند) شناسایی شدند. سپس، از خبرگان خواسته شد تا اثرات متقاطع، متغیرهای شناسایی شده را از طریق مقایسه زوجی ارزیابی کنند. درنهایت، تجزیه و تحلیل داده‌ها به روش تحلیل اثرات متقابل با استفاده از نرم‌افزار MICMAC انجام شد. بر مبنای تحلیل شبکه روابط اثرگذاری و اثرپذیری به‌ترتیب الزامات و چالش‌های اقتصادی، الزامات و چالش‌های فنی و زیرساختی، الزامات قانونی و مقرراتی و الزامات نهادی به‌عنوان تأثیرگذارترین متغیرهای مؤثر بر توسعه کشاورزی هوشمند در استان تهران شناسایی شدند.

واژه‌های کلیدی: الزامات هوشمندسازی، توسعه کشاورزی هوشمند، چالش‌های هوشمندسازی، گلخانه هوشمند

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