ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

**DOCTORAL (PHD) THESIS BOOKLET**

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# The paths to sustainable food security

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**DOCTORAL SCHOOL ON SAFETY AND SECURITY SCIENCES**

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# 1 Summary

This thesis explores sustainable food security through the lens of agricultural risks, food consumption behaviors, and individual awareness. It demonstrates that awareness of food safety and food security is strongly linked, yet often inconsistent with actual practices. Early education, especially on digital agriculture, food waste, and food security, is essential to raise awareness—particularly among younger, less-educated groups. Traditional education methods remain more effective than emerging tools like digital games.

Farmers and consumers are identified as the key actors across the food value chain. Digital agricultural technologies (DAT) are seen as crucial for improving production efficiency and sustainability, though adoption in Bayannur faces challenges such as an aging workforce and small-scale farming. Individual food consumption behaviors, particularly food waste, significantly affect food security. Demographic factors, dining habits, and behavioral interventions are closely linked to waste patterns, suggesting targeted strategies to reduce food loss.

## 2 Background of the Research

With the current growth of the population, between 2005 and 2050, the food demand will increase by 59 percent to 98 percent [1]. According to the data from 2020, 811 million people suffered from hunger, 3.1 billion people did not have a healthy diet, and 132 million people were threatened by food and nutrition insecurity because of the COVID-19 pandemic [2], [3]. The ongoing war [4], which started in February 2022 between two important world food suppliers, Russia and Ukraine, worsened the world's food security situation [5]. The so-called "World's bread basket" around the Black Sea has been in trouble since the war's outbreak [5], [6]. However, these two recent problems did not start the world food security dilemma. Instead, they have acted as catalysts [7]. For instance, global climate change and extreme weather [8], [9] threaten agriculture through their influence on ecology, the environment, the geographical situation of crop and crop production, the resources and supply chain of agriculture, and the market price [10].

Food loss and waste [11] is a broader topic related to global food security, food safety, quality, and sustainability. It is evident that reducing food

loss and waste is a triple win for food security, climate change, and sustainability [12].

There are three dimensions to sustainability: economic, social, and environmental. Food security requires sustainable food and agriculture. How to achieve sustainable food and agricultural development is everyone's duty on this planet for the current and next generations. In this thesis, the definition of food security comes from FAO, World Bank, and World Food Summit, which was first defined in the 1970s and improved to a more accurate and acceptable concept. It mainly refers to four aspects: food availability, food access, utilization, and food stability [13]:

- Food availability means an adequate food supply with proper, safe food.
- Food access promises everyone to access sufficient and nutritional food at the individual, regional, or national levels.
- Utilization refers to the food supplied to all people to meet nutritional requirements.
- Food stability requires availability and access for all people, even

in the shock of economic crises, climate crises, or seasonal food insecurity.

Food safety and food security are two main concerns in this topic, which are linked closely with each other. Food safety means that the food available for humans is safe, not harmful, and there is no contamination of food. When we talk about food security, we have to highlight that if there is no food safety, there will be no food security. In this thesis, I will mainly focus on food security.

## 3 Objectives

To explore the solutions to ensure sustainable food security and summarize a model to research the paths, three aims were structured according to the scientific problem and research gaps:

A1: To examine the food security crisis

A2: To explore the crucial role of education in increasing global citizens' awareness to ensure sustainable food security

A3: To identify farmers (from the perspective of digital agricultural production) and food consumers (from the perspective of food waste reduction) as the two most important roles in the food value chain to contribute to sustainable food security

In this thesis, six main research questions were posed to prove the research aims:

Q1. Should we be concerned about the food security crisis in our global village?

Q2. Is education in increasing awareness of food safety and food security important in ensuring sustainable food security?

Q3. What is the role of sustainable agriculture in ensuring food security?

a. Will sustainable/green food be welcomed?

Q4. What is the role of farmers in sustainable agriculture?

Q5. What is the role of food loss and waste in ensuring food security?

Q6. What is the role of each individual in food loss and waste?

## 4 Research Methods

This study combines secondary research with three primary investigations conducted in China in 2024. Using a multiple case study approach, it explores stakeholder awareness, farmers' perceptions of digital agricultural technologies (DAT), and the impact of food waste behavior on food security. Although the sample is not fully representative, it offers valuable insights. Data were collected through two questionnaires and one interview to enable a context-specific understanding of food security challenges. The logical relationship between different case studies or primary research is illustrated in Figure 1. The study examined the awareness of food safety and security among five key stakeholders in the food value chain: farmers, transporters, food processors, food service staff, and consumers. Findings highlighted farmers and consumers as the most critical stakeholders—farmers as producers and consumers as end-users. Consequently, the research focused on two key factors: farmers' perceptions of digital agricultural technologies (DAT) and consumers' demand for sustainable (organic) food and their food waste behaviors.

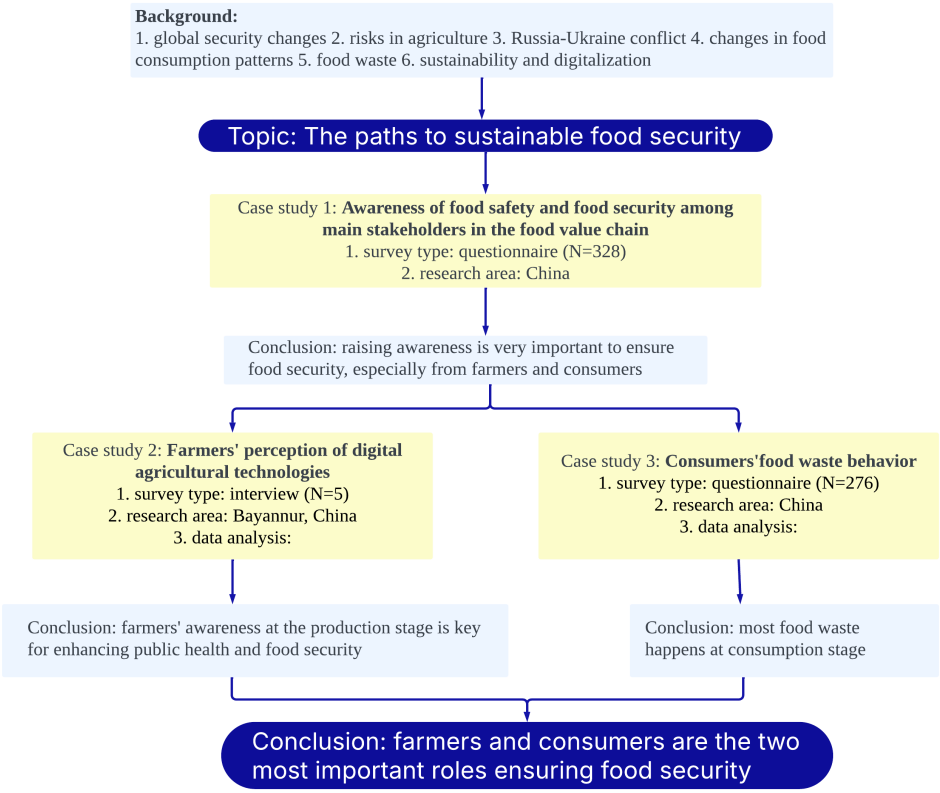


*Figure 1 Flow chart of the logic relationships among case studies*

Source: own construction

The literature review established the current food security crisis and the need for sustainable solutions through secondary and primary research. To assess awareness levels, a questionnaire evaluated the role of education among five key stakeholders in the food value chain: farmers, transporters, food processors, food service staff, and consumers. Secondary research underscored the importance of surveying these groups to understand their impact on food security. The conclusion highlights the roles of the two most critical stakeholders in ensuring food security, farmers (producers) and consumers, emphasizing their awareness, knowledge, and practices (Table 1). In some literature, different players' importance in ensuring food security across the food value chain was evaluated and marked with varying colors of depth.

*Table 1 The importance of different players' importance along the food value chain and awareness, knowledge, and practice summary*

| Players | Stage | Awareness, knowledge, and practice | |
|---|---|---|---|
| Farmers (Producers) | Production | • Climate change perception<br>• Sustainable biological and chemical control<br>• Knowledge and innovation in agriculture<br>• Importance of biosecurity<br>• Market demand | • Complying with regulations<br>• Participation in certifications<br>• Collaboration with other communities |
| Transporters (distributors) | Transportation (distribution) | • Significant logistical challenges<br>• High fuel costs and poor road conditions<br>• Lack of direct accountability and engagement in food safety | |
| Processors (food handlers) | Processing | • Storage conditions<br>• Operation sanitization<br>• Lack of research | |
| Food service staff (retailers) | Retail | • Adequate food safety knowledge and attitudes, but need more education and training to transform into practice | |
| Consumers | Consumption | • Food security awareness enhanced after COVID-19, but not food safety<br>• Hygiene practice | |

Source: author's own construction based on literature review chapter

The thesis focuses on the two ends of the food value chain ("from farm to table"), beginning with a questionnaire assessing all stakeholders' food safety and security awareness. After identifying farmers and consumers

as the most crucial players, follow-up research was conducted through in-depth interviews with farmers (production stage) and a consumer questionnaire (consumption stage) to examine their respective roles in ensuring food security.To achieve the research aims, various theories and methodologies were used in secondary research and primary research to answer the research questions (Table 2).

*Table 2 Summary of used theories and methodologies to answer the research question*

| Research aims | Research questions | Hypothesis | Used theories | Research methodologies used to justify hypothesis |
|---|---|---|---|---|
| **A1: To examine the food security crisis situation** | Q1. Should we be concerned about the food security crisis in our global village? | H1: There is a neccesity to obtain sustainable solutions to handle food security crisis. For instance, Russia and Ukraine are essential world food suppliers, and their conflict worsens the world food security crisis. | • Michael E. Porter's value chain theory<br>• Roger's Diffusion of Innovation Theory | • Cronbach's α analysis<br>• Time series analysis |
| **A2: To explore the crucial role of education in increasing global citizens' awareness to ensure sustainable food security** | Q2. Is education in increasing awareness of food safety and food security important in ensuring sustainable food security? | H2: Awareness is crucial to ensure food security, and the most effective way to raise awareness is education. | • Knowledge, attitudes, and practices model - CS 1. | • Cronbach's α analysis<br>• Chi-square analysis<br>• Pearson correlation analysis<br>• Cluster analysis |
| **A3: To identify farmers (from the perspective of digital agricultural production) and food consumers (from the perspective of food waste reduction) as the two most important food value chain roles to contribute to sustainable food security** | Q3. What is the role of sustainable agriculture in ensuring food security?<br>a. Will sustainable/green food be welcomed? | H3: Sustainability is necessary to ensure food security and green food is getting more and more welcomed by consumers. | Michael E. Porter's value chain theory | • Content analysis<br>• Spearman correlation analysis<br>• ANOVA analysis |
| | Q4. What is the role of farmers in sustainable agriculture? | H4: Farmers play a crucial role in food supply at the production stage and utilizing digital agricultural technologies to improve food production | Technology Acceptance Model - CS 2. | • Thematic Analysis<br>• Pearson correlation analysis |
| | Q5. What is the role of food loss and waste in ensuring food security? | H5: Food loss and waste are the biggest risk threatening food security, but everyone can contribute to reducing food waste. | CS 3. | • Cronbach's α analysis<br>• Pearson correlation analysis<br>• Ordinal logistic regression analysis<br>• Cluster analysis<br>• Decision tree analysis |
| | Q6. What is the role of each individual in food loss and waste? | | | |

*Source: author's own construction, $N_{CS\,1.}$=328 (2024), $N_{CS\,2.}$=5 (2024), $N_{CS\,3.}$=276 (2024)*

## 5 New Scientific Results

**1st thesis point: Based on the literature analyses, I created the Food Security Triangle Model (Figure 2), summarizing …… [publications connected ….]**

This thesis proposes the "Food Security Triangle Model", emphasizing that sustainable food security requires not only smart agricultural production, but also efficient food utilization and public awareness—forming three interdependent pillars for a resilient food system.

Before demonstrating the new scientific results of this thesis, I passionately put forward the research model, “Food Security Triangle Model” (Figure 2), about the paths to sustainable food security based on an extensive literature review and multiple primary research. The sustainable path to food security is not only guaranteed by the source of producing food (such as the modern and sophisticated smart agricultural technologies as a lot of valuable literature mentioned) but also by utilizing the food resources more wisely and efficiently across the entire food value chain (as it is explored and highlighted in this research, reducing food loss and waste is contributing to a more sustainable food

system and a stronger community). To ensure “producing more” from farmers and “waste less” from individuals, awareness and knowledge of food safety and food security are crucial.

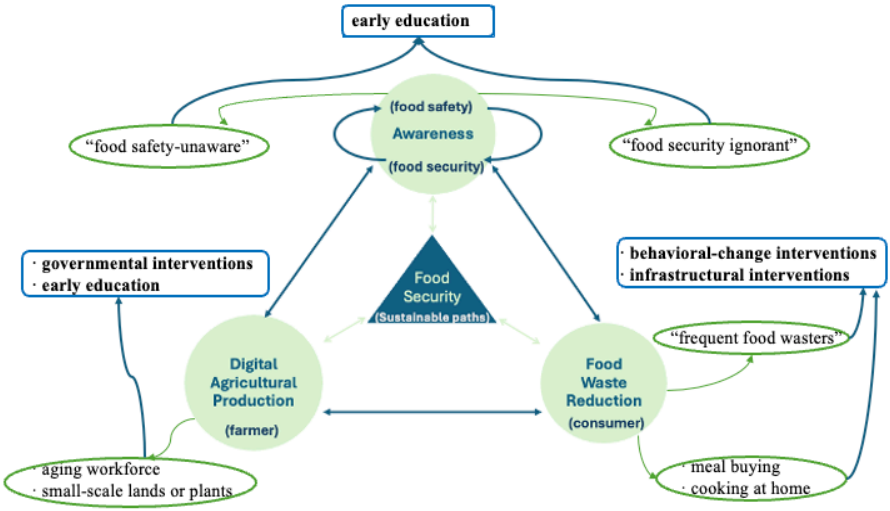


*Figure 2 Food Security Triangle Model*

Source: author’s own construction

Multiple research methods about food production quantity prediction, organic food consuming behavior, food safety, and food security

awareness evaluation, farmers' perception of DAT, and food waste behavior provided in this model can be repeated in different regions, different sample sizes, and different scenarios (such as food waste evaluation in household food and other food services in restaurants or retail).

**2nd thesis point: The crucial role of education in increasing individual awareness to ensure sustainable food security – Based on primary research, I proved that education plays a key role in shaping individuals' awareness of both food safety and food security, while socio-demographic factors such as age, income, occupation, and place of residence further influence this awareness. [related publications:** Pál, B., **Wu, Y**., & Takács-György, K. 2023 [147]; **Wu, Y**. 2022 [93]; **Wu, Y**., Pál, B., & Takács-György, K. 2024 [112]; **Wu, Y**., & Zhong, X. 2022 [104]; Zhong, X., & **Wu, Y**. 2022 [105], **Y. Wu** and K. Takács-György. 2024 [114].**]**

Although respondents report relatively weak awareness in both areas, their actual practices regarding food safety and food security are more positive, indicating a clear gap between knowledge and behavior.

Individuals who are more aware of food security also tend to be more aware of food safety, suggesting a strong correlation between the two domains. Among different actors in the food value chain, food processors and food service staff are most commonly viewed as primarily responsible for ensuring food safety and food security.

Cluster analysis identified two main groups: (1) food safety-conscious individuals, who are generally older, urban, better educated, and employed with higher income, and (2) food safety-unaware individuals, who are younger students with lower income and education levels. A similar clustering was observed for food security awareness: the "aware" group consists of older, urban, educated, and employed individuals, while the "ignorant" group includes younger rural residents with lower educational backgrounds and limited income. Education, occupation, and income consistently emerged as the most significant distinguishing factors between clusters.

In terms of raising public awareness, respondents largely favored traditional methods such as early education and government-led campaigns. More modern strategies, such as digital games or influencer

outreach, received mixed responses and were generally seen as less effective. These findings highlight the enduring value of conventional education strategies in enhancing food-related awareness, particularly among younger or less-informed populations.

**3rd thesis point: Farmers' role in ensuring food security from the perspective of digital agricultural production - With scientific methods, I have proved that although the use of digital agricultural technology (DAT) in Bayannur is still at an early stage, many farmers—especially those born after the 1990s—have a positive attitude toward using it, mainly because they believe it can make farming more efficient and scientific. [related publications:** Vuka, E., & **Wu, Y**. 2024 [147]; **Wu, Y**. 2022 [142]; **Wu, Y**., & Liu, Y. 2022 [143]; **Wu, Y**., & Takács-György, K. 2023 [141]; **Wu, Y**., & Takacs-Gyorgy, K. 2023 [146]; **Wu, Y**., & Zhong, X. 2022 [115]; **Wu, Y**., Zhong, X., & Takács-György, K. 2023 [140]**.**

Surprisingly, high cost is not the main problem. The biggest challenges are the aging workforce, low digital skills, and the difficulty of using DAT on small farms. Support from families and local communities helps

farmers decide whether to adopt these technologies. In addition, men and women often have different views on DAT, which suggests the need for more inclusive approaches. Government policies such as land transfer programs, export support, and face-to-face training are very helpful in promoting DAT use. Shared use systems and early education about DAT, food waste, and food security also help increase awareness and make DAT more accessible. These results show that the shift to digital farming depends not only on technology but also on social and policy support.

**4th thesis point: Individual responsibility in ensuring food security from the perspective of food waste reduction – Based on a statistical analysis of survey data in China, this study confirms that food waste is a widespread issue influenced by individual behavior and perception. Both the frequency and amount of food waste are closely associated and are significantly affected by demographic variables, eating habits, awareness, and attitudes. [related publications: Wu, Wu, Y.**, & Nagy, R. 2022 [156]; **Wu, Y.**, & Takács-György, K. 2023a [155]; **Wu, Y.**, & Takács-György, K. 2023b [158]; **Wu, Y.**, & Takács-György. 2023 [157].

The frequency of food waste is negatively related to age, religion, awareness of food waste problems, and understanding of the economic benefits of reducing waste. In contrast, it is positively associated with bread consumption, awareness of social benefits (e.g., reputation), and familiarity with international food waste definitions. Similarly, the amount of food waste decreases among urban residents, those who regularly consume staple foods (e.g., rice, noodles, fish), and individuals who perceive food waste as an ethical or environmental issue. In contrast, rural residents, higher-income groups, and those who consume more meat, dairy, and vegetables tend to waste more food.

Behavioral patterns such as over-ordering, large portion sizes, and dissatisfaction with food quality are identified as key reasons for waste. Effective interventions include planned food purchasing, proper portioning, educational prompts, and infrastructure adjustments in dining environments. Strategies like trayless dining and takeaway options have moderate effects, while others—such as composting or waste contractor involvement—show mixed or limited impact.

Cluster analysis identifies two main consumer groups: frequent food wasters and conservative wasters, with significant differences in age, income, location, education level, diet, and confidence in meal completion. Decision tree analysis further reveals that dining habits, shaped by economic conditions, are closely tied to waste behavior, highlighting the role of targeted interventions in both domestic and institutional settings.

## 6 Possibility to utilize the Results

The methodology and analytical framework developed in this thesis on sustainable food security pathways are adaptable for use in other countries and regions beyond China. It offers a replicable model for future research and supports comparative studies using similar approaches.

Several research topics emerging from this work, though not fully explored, present valuable directions for future study:

1. Comparative analysis of actual and forecasted major crop exports (2022–2024) to assess the global impact of the Russia–Ukraine war.
2. Challenges and strategies in digital agricultural education to support wider DAT adoption.
3. Investigations into data security risks in agricultural technologies (e.g., 5G, GPS) to inform policy.
4. Improved measurement of food waste using direct weighing and photographic methods, alongside reduction strategies.
5. Examination of food safety awareness among underrepresented

actors in the food value chain, such as transporters and processors.

6. Risk assessment of emerging technologies (e.g., quantum machine learning for crop disease detection) in agricultural applications.

It is important to note that due to sampling limitations, some findings may reflect regional characteristics, such as those of Bayannur agricultural practitioners. Nonetheless, the empirical results offer meaningful insights for policy development in digital agriculture and food waste reduction, with potential for broader application in future studies.

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# 8 Publications

## 8.1 Scientific Publications related to the Thesis Points


1. E. Vuka and **Y. Wu**, “What is stopping digital agricultural production technologies from farmers,” in IEEE 24th International Symposium on Computational Intelligence and Informatics (CINTI 2024) : Proceedings, 2024, pp. 179–184.
2. **Y. Wu,** B. Pál, and K. Takács-György, “The Necessity of Sustainable Agriculture from the Perspective of the Importance and Risks of Agriculture for a Country: A Comparative Research,” in Farm Machinery and Processes Management in Sustainable Agriculture, 2024, pp. 448–461.
3. **Y. W**u, “Mobile Communication Evolution and the development of 5G in China,” HÍRVILLÁM = SIGNAL BADGE, vol. 2024, no. 1, pp. 167–178, 2024.
4. B. Pál, **Y. Wu**, and K. Takács-György, “A fenntartható mezőgazdaság és annak kihívásai egy ország számára : szakirodalmi áttekintés Kína és Dél-Korea esettanulmányain keresztül,” EURÁZSIA SZEMLE, vol. 3, no. 3, pp. 130–152, 2023.
5. **Y. Wu** and K. Takács-György, “Why does food loss and waste matter for food security - from the perspective of cause and magnitude,” ECOCYCLES, vol. 9, no. 3, pp. 47–61, 2023.
6. **Y. Wu** and K. Takács-György, “Sustainable paths to food security from the perspective of food loss and waste management,” in IEEE 21st International Symposium on Intelligent Systems and

Informatics (SISY 2023), 2023, pp. 437–443.
7. **Y. Wu** and K. Takács-György, “What is stopping Agriculture 4.0?---Examples from China,” in IEEE 17th International Symposium on Applied Computational Intelligence and Informatics SACI 2023 : Proceedings, 2023, pp. 511–518.
8. **Y. Wu**, X. Zhong, and K. Takács-György, “Digital agricultural education in Hungary,” GRADUS, vol. 10, no. 1, 2023.
9. **Y. Wu** and K. Takács-György, “The challenges of food security from the perspective of food loss and food waste,” BIZTONSÁGTUDOMÁNYI SZEMLE, vol. 5, no. 1, pp. 11–24, 2023.
10. **Y. Wu** and K. Takács-György, “Information security of food security,” in IEEE 21st World Symposium on Applied Machine Intelligence and Informatics SAMI (2023) : Proceedings, 2023, pp. 261–266.
11. **Y. Wu** and X. Zhong, “What are the challenges and opportunities in agribusiness: in the post-covid-19 era?,” in XVIII. Nemzetközi Tudományos Napok [18th International Scientific Days] : A „Zöld Megállapodás” – Kihívások és lehetőségek [The ’Green Deal’ – Challenges and Opportunities] : Tanulmányok [Publikcations]., 2022, pp. 734–740.
12. **Y. Wu**, “The general overview of water resources uses in the agricultural sector in china: status, challenges, actions and reform of government policy, achievements and future in water resource,” in XVIII. Nemzetközi Tudományos Napok [18th International Scientific Days] : A „Zöld Megállapodás” – Kihívások és

lehetőségek [The ’Green Deal’ – Challenges and Opportunities] : Tanulmányok [Publikcations]., 2022, pp. 721–727.
13. **Y. Wu**, “PURSUING SUSTAINABLE FOOD PRODUCTION WITH PRECISION AGRICULTURE,” in XVIII. Nemzetközi Tudományos Napok [18th International Scientific Days] : A „Zöld Megállapodás” – Kihívások és lehetőségek [The ’Green Deal’ – Challenges and Opportunities] : Tanulmányok [Publikcations]., 2022, pp. 714–720.
14. **Y. Wu** and X. Zhong, “Manifestations of Sustainable Development in China: Based on Policy Study,” ECONOMIC AND REGIONAL STUDIES / STUDIA EKONOMICZNE I REGIONALNE, vol. 15, no. 3, pp. 269–283, 2022.
15. X. Zhong and **Y. Wu**, “How does China respond to the agricultural commodities market: A case study in the post COVID-19 era?,” in MEB — 20th International Conference on Management, Enterprise, Benchmarking. Proceedings (MEB 2022), 2022, pp. 19–28.
16. **Y. Wu**, “New page of agriculture: on the view of 5G generation and GPS,” in 10th IEEE Jubilee International Conference on Computational Cybernetics and Cyber-Medical Systems, ICCC 2022, 2022, pp. 105–110.
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## 8.2 Additional Scientific Publications

21. **Y. Wu**, T. Babos, and K. Takács-György, "Global security changes and trends," in IEEE 22nd International Symposium on Intelligent Systems and Informatics (SISY 2024), 2024, pp. 195–200.
22. **Y. Wu**, L. Hanka, and K. Takács-György, "Changes in the crop world market: what will be the food supply without the russia-ukraine war?," BIZTONSÁGTUDOMÁNYI SZEMLE, vol. 6, no. 1, pp. 9–26, 2024.
23. **Y. Wu** and Z. Rajnai, "5G Standardisation: case study in China," in IEEE 22nd World Symposium on Applied Machine Intelligence and Informatics : SAMI 2024 : Proceedings, 2024, pp. 133–138.
24. **Y. Wu**, B. Tibor, and K. Takács-György, "The importance of agriculture, in the light of global security changes and trends," NATIONAL SECURITY REVIEW : PERIODICAL OF THE MILITARY NATIONAL SECURITY SERVICE, vol. 2023, no. 2, pp. 80–99, 2023.
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Russia-Ukraine War," BIZTONSÁGTUDOMÁNYI SZEMLE, vol. 5, no. 3, pp. 107–117, 2023.
26. A. Nagy, **Y. Wu**, K. Takács-György, Z. Rajnai, and B. Fregan, 'Glance at Quantum Innovations in Crop Pest and Disease Detection: Bridging Physics and Agriculture', in 2025 IEEE 23rd World Symposium on Applied Machine Intelligence and Informatics (SAMI), Stará Lesná, Slovakia: IEEE, Jan. 2025, pp. 000289–000292. doi: 10.1109/sami63904.2025.10883296.
27. Y. Wu, Attila Nagy, Zoltán Rajnai, Fregan Beatrix, and Katalin Takács-György, 'Quantum Machine Learning in Crop Disease Monitoring: Opportunities and Challenges to Practical Implementation', in IEEE 12th International Joint Conference on Cybernetics and Computational Cybernetics, Cyber-Medical Systems (ICCC 2025) : Proceedings, 2025, pp. 59–63.

*To my supervisor, Dr. Takácsné Prof. Dr. György Katalin and me, Wu Yue.*

*This is my Ph. D thesis, but a 4-year continuous mutual work results from us.*