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The paths to sustainable food security

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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.

CONTENT

1 INTRODUCTION

1.1 The scientific problem statement

It is estimated that the global population will be 9.1 billion in 2050, 34% higher than today in 2050, which, together with the rapid increase in food prices, results in a vast number of hungry and malnourished people worldwide [1], [2]. The BRICS countries' population can reach almost half of the global population in 2050, which also means potential agricultural labor force and potential economic opportunities [3]. Between 2005 and 2050, the food demand will increase by 59 percent to 98 percent with the growth of the population [4]. According to the data from 2020, on the same planet, 811 million people are suffering from hunger, 3.1 billion people do not have access to a healthy diet, and 132 million people are threatened by food and nutrition insecurity because of the COVID-19 pandemic [5], [6]. What is worse, the ongoing war [7] started in February 2022 between two important world food suppliers, Russia and Ukraine, worsening the world's food security [8]. These two countries are the top producers of world foodstuffs and fertilizers, besides, Russia is also the main supplier of oil and gas [9]. The so-called "World's bread basket" around the Black Sea has been in trouble since the war outbreak [8], [10]. But these two rigorous and unpredictable problems are not the start of the world food security alarm, catalysts instead [11]. For example, global climate change and extreme weather [12], [13] 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 [14]. Plant diseases cost 220 billion dollars around the world [15]. The food production loss caused by disease accounts for 14% of the total global food production, and the food production loss caused by pests is 10% of the global food production [16]. Natural resource scarcity (arable lands and water) [13], [17], agriculture facilities issues (aging farmers and fewer farmers because of urbanization) [17], [18], [19], and food market fluctuation [20] are also the main causes of agricultural risks.

Food loss and waste [21] is a broader topic related to global food security, food safety, quality, and sustainability. The food loss and waste policy is suggested as the primary driver of food security and the second most recommended policy after food security [22] as it is one of the solutions for ensuring food security [23], [24]. According to the estimation of FAO, every year lost and wasted food can feed 1.26 billion hungry people. From a worldwide view, every year, the food loss and waste is approximatey14%, valued

at $400 billion after harvest and before market. And 17% or 931 million tonnes of food is lost between market and consumption, such as households, restaurants, retailers, and other food service types, especially households (11 percent in households, 5 percent in the food service, and 2 percent in retail) [5], [6], [25], [26], [27]. And 8-10 percent of global greenhouse gas emissions (GHGs) are from food loss and waste, which worsen the unstable climate and extreme weather. Vice versa, the more unstable climate change and extreme weather negatively impact crop production and crop yields [6], [26]. The greenhouse gas emission ranks after China and the US [28]. It is obvious that reducing food loss and waste is a triple win for food security, climate change, and sustainability [26].

People need to be offered enough food and a healthy diet in a safe nation and state. In 2015, the UN announced the 2030 Agenda for Sustainable Development, an action guide for the international community to 2030, which aims to end poverty and hunger. There is three-dimensional sustainability: economic, social, and environmental. And the 2030 agenda offers a vision that food and agriculture are the heart of sustainability development [29]. Food security requires food and agriculture sustainability. 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 [30]:

- 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.

Both food safety and food security are two main concerns in this topic, which are linked closely with each other. Food safety means the available food for humans is safe, not harmful, and there is no contamination of food. If we talk about food security, we have

to highlight that if there is no food safety, there will be no food security. But in this thesis, I mainly focus on the topic of food security.

1.2 Research gap

The importance of agriculture in light of global security changes and trends:

The existing research usually studied the global security global security changes and trends, and risks in agriculture separately. Few research highlights the essential interrelated relationship between agriculture and global security, such as climate change and extreme weather. Ensuring food security is not only a concern of big populated countries or countries depending on agriculture but every global citizen's responsibility.

Food security awareness of the main players across the food value chain:

Food safety and food security are closely linked, but surveys about awareness of food security and food safety are usually two separate topics and food security gets relatively less attention. Regarding the awareness of different players in food safety and food security, the existing research is not distributed evenly at different stages, and most research focuses on the retailer and consumption stages [31] instead of the production stage. Different stakeholders' awareness of food safety and food security will be important to understand the factors influencing stakeholders' sustainable food security attitudes and behavior.

Entire food value chain resilience and integrating sustainable food security policy:

The isolated food value chain stages are usually researched to address food security issues. A comprehensive research focusing on the entire food value chain by examining the main players' roles against the risks is scarce. An integrating solution involving the entire food value chain can be effective in realizing resilient food security, such as integrating diverse policy aspects, including agricultural production, trade, and education.

Farmers' perception of digital agricultural technologies and digital agricultural education:

Nowadays, digital technologies play a vital role in agriculture to provide food production. However, the transformation to the digital agriculture stage is slow. The literature on the adoption of some digital technologies is scarce. Addressing the topic involves several strategies to deepen understanding and gather insights. Conducting original research or advocating for more studies in this domain makes significant contributions to the field.

Even though digital agriculture is so important that many scholars have studied it from various aspects, there is only a little attention on the education of digital agriculture. Obstacles to the development of digital agriculture which has inevitably led to the creation of digital agricultural education. However, there are few papers about it and certain challenges for educators or trainers.

Food waste behavior in institutions:

With the changes in food consumption, eating in institutions or companies is becoming as popular as eating at home. While the drivers of food waste have been extensively studied in household settings, there is limited research on these factors in institutional environments such as university dining commons [32].

Prosperity of emerging technologies:

The modern technologies utilized in precision agriculture and digital agriculture have gotten quite a quantity of research, while few studies explore the possibility of quantum machine learning. Nevertheless, the application, benefits, and challenges of quantum machine learning are not common fields of research. Though the practical challenges of utilizing quantum machine learning in agriculture to protect food production restrict its future, it is still worth having a brave look at the prosperity brought by it.

All of these research gaps represent a potential urgency to research the paths to ensure food security for a region and the world.

1.3 Research aims

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 situation

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 food value chain roles to contribute to sustainable food security

1.4 Research questions

In this thesis, six main research questions were provided 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 shot 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 shot of food loss and waste in ensuring food security?

Q6. What is the role of every global citizen in food loss and waste?

2 LITERATURE REVIEW

To achieve the research aims of this thesis, an extensive literature was reviewed and summarized by the order of three topics: the importance and risks in agriculture, sustainability and digitalization in agriculture and food, and changes in food consumption.

2.1 The importance and risks of agriculture

Agriculture has changed human life from a nomadic to a permanent settlement lifestyle since 12,000 years ago [33]. A stable food supply is guaranteed when animals and crops can be farmed and meet the demand [34] . The evolution of Agriculture 1.0 started in the early 1900s [35]. Thanks to the Industrial Revolution, agriculture experienced its 2.0 era in the late 20th century. The Agriculture 3.0 revolution, also called precision agriculture, happened due to the rapid development of intelligent applications in the 1980s, such as sensors, robotics, satellite imagery, and field mapping [36]. Therefore, crop quality and profitability could improve, and some sustainable agricultural problems can potentially be solved. Agriculture 4.0, or smart agriculture or digital agriculture, has been the product of developing digital technologies and improving precision agriculture since the 2010s, such as IoT, big data, cloud computing, AI, 5G, etc. [37].

In developing countries, the productivity of agriculture is responsible for both rural and urban poverty [38]. Agriculture contributes 4% to the global gross domestic product (GDP) and can account for up to 25% in certain developing countries [39], which plays a crucial role. In some developing countries, agriculture contributes the most job opportunities than other sectors, such as industry, construction, transportation, etc. [40]. Agriculture is especially important in rural small-scale family farming [41]. The role of agriculture for locals beyond economics where got less attention relatively [42], [43]. In terms of social function or social stability, the most important function of agriculture is maintaining food security [44]. For locals, agriculture guarantees the local high-quality food, contributes to the community and quality of life, and maintains important traditions, heritage, and work ethic [42]. Nowadays, as more and more attention is paid to renewable energy, agriculture is an important source of renewable energy, which is called bioenergy, ensuring some countries' energy security [45]. The third basic foundation of agriculture that is usually discussed is environmental function. For example, agriculture preserves wildlife [43], and the ecosystem provides bucolic views [42] and reduces GHG (CO2)

and risks of floods [46]. Instead of the pollution from waste, waste can be collected, composted, and reused in agriculture [47].

Under the global security changes and trends background [48], [49], agriculture has been and will be exposed to various threats and risks obviously (climate change, biodiversity loss, natural risks and disasters, health security, aging farmers, energy supply, infrastructure security, limited resources, increasing food demand due to increasing population, market fluctuations, etc.). Two of the biggest problems in agriculture are water scarcity and soil degradation. Drought is becoming serious due to misuse and pollution, resulting in 9 lakes disappearing already, and some lakes have lost 90% of water in the world. Soil degradation in terms of loss of soil fertility and soil biodiversity. People's lack of water-saving awareness and knowledge also cause big water waste problems [50]. It is reported that 30% of farmland has been unavailable in the last forty years. If this rate continues, all of the world's topsoil will be unavailable in 2080 [51]. The safety and security of a country or region, risks from globalization, international and local policy background, and requirements for sustainable development also influence agriculture

2.2 Sustainability and digitalization in agriculture and food

The transformation of every element of the business, government, and society based on the widespread application of both established and emerging digital technologies is referred to as "digitalization" [52]. From a fundamental point of view, digitalization is the act of turning information into a digital (i.e., computer-readable) format and making it available on digital devices for faster, more convenient reading [53]. Digitalization has undergone a transformation and has been used in a variety of industries, and it is now widely acknowledged as a potent tool for development in most areas [54], [55], [56], [57]. Among many of the applications of digital transformation, digital agriculture has received great attention as one of the core studied objectives[58], [59], [60], which is a tool that digitally collects, stores, analyzes, and shares electronic data and/or information in agriculture associated with digital technologies such as GPS, drones, sensors, etc. [58] to support the sustainability of the economy, society, and environment by increasing productivity and efficiency and decreasing the cost and waste [61], [62], [63], [64],[65], [66]. Climate-Smart Agriculture (CSA) is an approach that includes traditional organic farming and innovative technologies and Information technology (IT) to transform agriculture production and agrifood value chain to the direction of sustainable

development facing climate change, which was introduced by FAO in 2010 and support the SDGs and The Paris Agreement [12], [67]. Digitalization is not just a new sector in agriculture but also a booster for a nation's economy. Building digital agriculture is becoming a national strategy in economies such as China and Russia [68].

The use of machinery in agriculture, such as the intensive tractor, combine harvesters, and trucks, can improve crop production per unit of equipment by 19%-26% approximately and decrease the cost of per unit production [69]. It can also significantly reduce soil disturbance and degradation and, on the other hand, protect soil fertility [70]. Drones, GPS, and other IoT used in yield monitoring and disease observation significantly decrease the operation time and increase the yields [71]. The advanced technologies used to analyze historical data and predict, such as big data and databases, can help farmers decide what crops and where to cultivate in a given climate zone, which can enhance biodiversity [71]. Digital technologies used in husbandries, such as radio frequency identification (RFID) and automated or robotic milking and feeding systems, improve efficiency and reduce the cost of quantity and quality as well [37]. In comparison to crop production, labor productivity is relatively lower in animal husbandry [69], but still, digital animal husbandry has a promising future for sustainable food security and food safety.

Digital agriculture can avoid some negative impacts from traditional agriculture [12], but we will face some challenges and security issues from the application, which we are not perfect at so far [72]. For instance, farmers must improve or acquire new digital skills and capacities in order to prepare for the impending digital shift. Regarding talent, there are two issues: on the one hand, the "new farmers" lack the knowledge and skills necessary, and on the other, farmers and small and medium-sized agricultural businesses need a thorough understanding of digital agriculture. DAE can offer a fresh opportunity to make learning new information and abilities in digital agriculture more convenient with regard to this problem. The use of innovative educational techniques and models, such as creating personal learning environments or personal learning clouds, is also made possible by information and communication technology tools. However, people's perceptions of DAE are still based on what is taught about it in schools and how education benefits digital agriculture, according to the scant study on this topic [73], [74]. Since DAE is a brand-new concept, there is no clear description of it as of yet. It was

emphasized that digital agriculture education is important to adopt digital technologies in agriculture in this thesis, but not a focus.

2.3 The changes in food consumption

It is common for most countries that the demand for food is the quantity and high quality. More nutritional, fresh[75], and healthy food [76] are becoming needed among consumers. According to the report from FAO, the world population keeps growing, and the income is also increasing, people's diet needs are also changing. People are becoming aware of environmentally sustainable and healthier diets. Organic food is the most successful green food (regarded as a buying behavior for the belief in a healthy life, the welfare of production animals, and a friendly environment), and organic farming is one of the sustainable agriculture production management systems [77], [78], [79].

People are adapted to a new lifestyle and food habits during the long period of the COVID-19 pandemic. Review the influential worldwide pandemic or historical crisis, the events 2002-04 SARS outbreak, the 2011 Christchurch earthquake, 2017 Hurricane Irma, and the COVID-19 outbreak in China negatively impact global economies. So far, COVID-19 has played the most harmful role worldwide, and it is changing people's buying behavior significantly [27], [28], [29]. Before, buying organic food was just a behavior among the middle class, but nowadays, the pandemic promotes the popularity of this thought to the more common class. Even with the price volatility and future income, consumers will shift to buy more nutritious and sustainable food. This change in buying behavior has already lasted more than three weeks, which is the time length that a habit can be formed [80].

With the pressure of increasing population[81], [82], the rapid development of urbanization[83], [84], [85], climate change[83], [86], [87], [88], natural disasters[89], [90], [91], [92], [93], food insecurity emphasized, and the demand for food increased, and the food consumption pattern changed. Dining out is becoming as popular as dining at home, which results in diverse types of food waste. According to the Waste and Resources Action Programme (WRAP), 26% of food waste generated in restaurants is unavoidable [94]. As the State of Food and Agriculture (2019) report from FAO, food loss and waste refer to a decrease in the quantity or quality of food along the food supply chain [95]. The distinctions between food loss and food waste exist in the conceptual framework and a policy aspect. Food loss comes from the food supply chain, excluding any consuming

step, including retail, food service offers, and consumers, where there is reducing of food in quantity and quality. Food waste refers to the step of consuming where food is decreased in quantity and quality, including the retailers, consumers, and other food service providers. However, there are still food waste reduction strategies that can be utilized in everyday life, which have potential value to research. A good awareness makes sure a good behavior. The 29 November International Day of Awareness of Food Loss and Waste (IDAFLW) was designed by the United Nations General Assembly in 2019, calling all the public and private sectors to work together on cutting food loss and waste to use the limited natural resources more efficiently, mitigate the burden from climate change, and obtain sustainable food and nutrition [27].

2.4 Hypotheses

The above literature review provides a strong foundation for the research aims and questions outlined in this thesis. Furthermore, five hypotheses have been developed as follows:

H1: There is a necessity to obtain sustainable solutions to handle food security crises. For instance, Russia and Ukraine are essential world food suppliers, and their conflict worsens the world food security crisis.

H2: Awareness is crucial to ensure food security, and the most effective way to raise awareness is education.

H3: Sustainability is necessary to ensure food security and green food is getting more and more welcomed by consumers.

H4: Farmers play a crucial role in food supply at the production stage and utilizing digital agricultural technologies to improve food production

H5: Food loss and waste are the biggest risk threatening food security, but everyone can contribute to reducing food waste.

3 MATERIALS AND METHODOLOGY

3.1 Thesis design and the structure of the primary research

To answer the research questions comprehensively and convincingly, both secondary research review and primary research were conducted during the Ph. D study. Due to the sampling method in primary research, the sample cannot be considered representative, but it gave a good base to discover the research questions. The logical relationship between different case studies or primary research is illustrated in Figure 1. As the logical relationship among case studies demonstrated, farmers produce food, and consumers eat the food produced by farmers. So, the two direct factors impacting food production and food security, farmers' perception of digital agricultural technologies (DAT) and consumers' demand for sustainable food (organic food) and consumption habits (food waste behavior), were investigated.

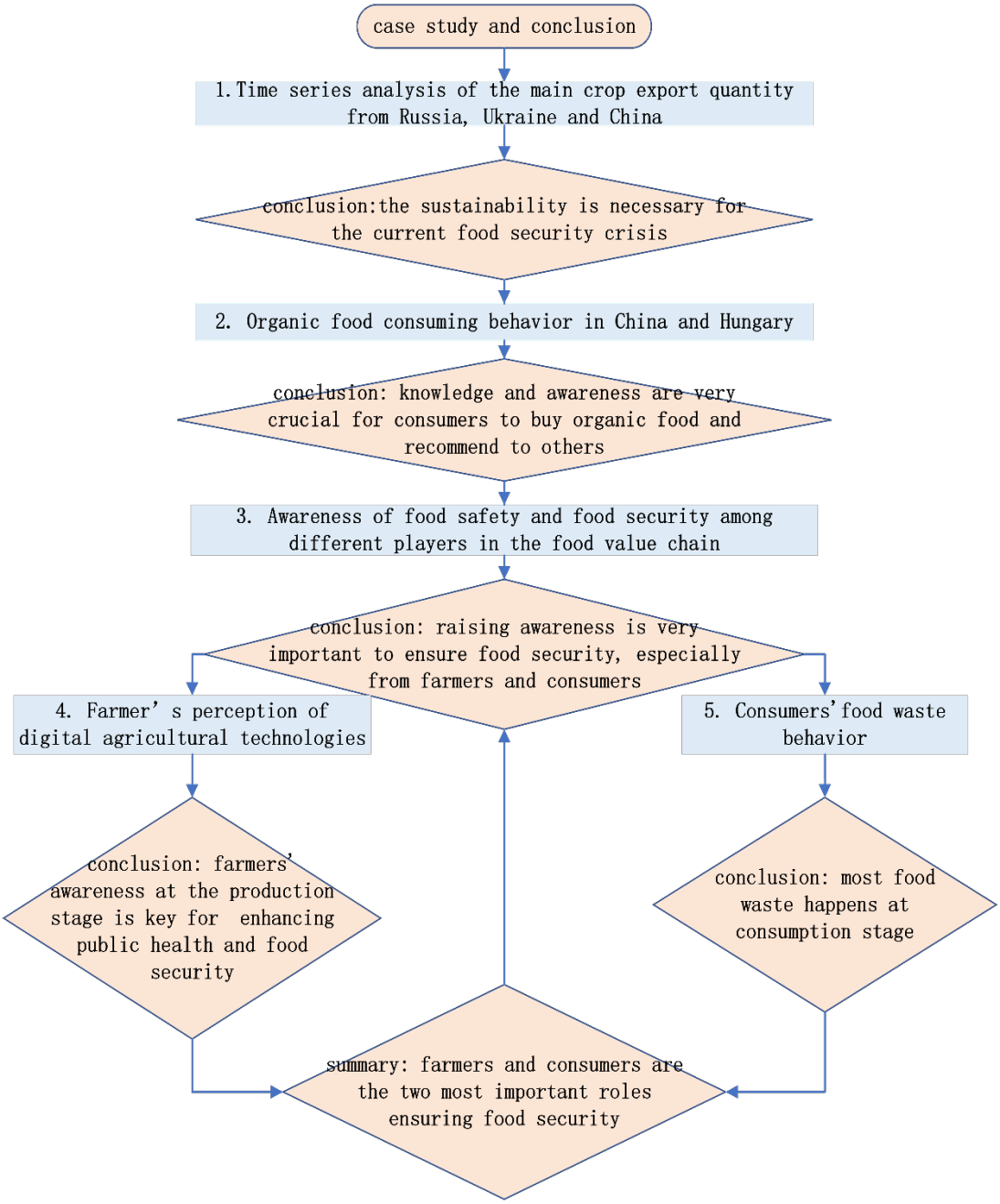

Figure 1 Flow chart of the logic relationships among case studies
Source: own construction

Firstly, the current food security crisis and the necessity of sustainable solutions were proved by secondary research and primary research. Secondly, the crucial role of education in increasing global citizens' awareness to ensure sustainable food security was conducted by researching different players in the food value chain about their awareness of food safety and food security. The need for conducting this primary research was highlighted by secondary research about the necessity of surveying different players' awareness of food safety and food security along the food value chain. It concluded the two most critical players, farmers' (producers) and consumers' roles and awareness,

knowledge, and practice in ensuring food security (Table 1). Different players' importance in ensuring food security across the food value chain was evaluated and marked with different colors of depth.

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

<table>
<tr><th>Players</th><th>Stage</th><th colspan="2">Awareness, knowledge, and practice</th></tr>
<tr><td>Farmers (Producers)</td><td>Production</td><td>• Climate change perception
• Sustainable biological and chemical control
• Knowledge and innovation in agriculture
• Importance of biosecurity
• Market demand</td><td rowspan="4">• Complying with regulations
• Participation in certifications
• Collaboration with other communities</td></tr>
<tr><td>Transporters (distributors)</td><td>Transportation (distribution)</td><td>• Significant logistical challenges
• High fuel costs and poor road conditions
• Lack of direct accountability and engagement in food safety</td></tr>
<tr><td>Processors (food handlers)</td><td>Processing</td><td>• Storage conditions
• Operation sanitization
• Lack of research</td></tr>
<tr><td>Food service staff (retailers)</td><td>Retail</td><td>• Adequate food safety knowledge and attitudes, but need more education and training to transform into practice</td></tr>
<tr><td>Consumers</td><td>Consumption</td><td colspan="2">• Food security awareness enhanced after COVID-19, but not food safety
• Hygiene practice</td></tr>
</table>

Source: author's own construction

Therefore, the core objects in the thesis are the starting and ending points of the food value chain, also known as "from farm to table." The following primary research was extended on this initial finding. One primary research (in-depth interview) targeted farmers at the production stage (farm), and the other two primary research (questionnaire) aimed at consumers at the consumption stage (table).

3.2 Case study objective selection and background

3.2.1 Case study in China

Most of the case studies focused on China, but other countries were also mentioned in this thesis. China is a developing country with a 1.398 billion population, and the GDP has been increasing fast in recent decades. China is the country that highlighted sustainable development in ancient times and has made effective policies with positive feedback in domestic China and worldwide, such as the Rural Revitalisation Strategy, Carbon Peak and neutrality plan, Belt and Road Initiative, active participation in the 2023 Agenda Sustainable Development Goals, Promotion of building a Community with a Shared Future for Mankind, and so on [96]. However, the consumption of organic food

is not widespread yet, and the domestic organic market is small but growing slower than in Hungary [83],[101],[99].

China, the sixth country with the biggest amount of water (6% of the total world water resource) [100], has a rich water resource, but the per capita possession is only 25% of the world average. It is surveyed that China is one of the most water-scarce countries and about 1/3 of agricultural lands are in water scarcity status [50]. Agricultural water use accounts for around 60% of the total water resource, and water efficiency in agricultural irrigation is only 54.2%. Besides, the precipitation and water resource distribution are uneven.

In China, the agricultural land system is characterized by the separation of land ownership rights, contract rights, and management rights [101]. The state or collective technically owns the land, but the rural households hold long-term, inheritable land-use rights, which can be transferred or leased. This agricultural land system is called the Household Responsibility System. However, the fragmentation of agricultural lands hampers agricultural efficiency and limits economies of scale as most farming work is conducted on small and scattered plots by small households. In China, the unit of land measure is Mu, and per Mu consists of 0.0667 ha. The average farm size is no more than 0.5 hectares per household [97]. The current Farmland Rights Confirmation Policy (FRCP) [102] is a crucial component of the country's broader rural land system reforms, and it aims to clearly define land-use rights for rural farmers, enhancing tenure security and encouraging more efficient land use. This policy has positively influenced land leasing-in behavior by providing security and incentives for farmers to expand their production. In recent years, the Circulation (transfer) of Rural Land Contracting and Management Rights (CRLCMR) [103] refers to the right to possess, use, and benefit from rural land while maintaining the ownership of the land by the state or collective. This policy can effectively improve land use efficiency, promote agricultural modernization and the use of advanced technologies, promote large-scale and mechanized farming, and increase farmers' income by allowing the consolidation and flexible transfer of land-use rights, supporting rural economic development.

China and India lead globally in household food waste production, generating an estimated 92 million and 69 million metric tons annually, respectively. This trend is expected, given their status as the world's most populous countries. While food waste has

traditionally been associated with wealthier nations, per capita food waste production shows similarities between developed and developing countries.

3.2.2 Case study in Bayannur

The interview about agricultural practitioners' perception of digital agricultural technologies focused on Bayannur, a city in the central and western part of the Inner Mongolia Autonomous Region, north China [104], [105] , with a population of 1.67 million population and a large portion of the farming activities population. It is one of China's most significant grain and sunflower oil production hubs. The city of Bayannur benefits from abundant agricultural resources due to the flow of the Yellow River through its territory. A significant aspect of this agricultural richness is the Hetao Irrigation Area, situated within Bayannur, which has long utilized water diverted from the Yellow River for irrigation purposes. The history of the Hetao Irrigation Area can be traced back to the Qin Dynasty (221 B.C.-206 B.C.) and was recognized as one of the World Heritage Irrigation Structures in 2019, utilizing gravity to channel water from the Yellow River into agricultural fields. The Hetao Irrigation Area has spanned 769,333.8 ha and has consistently produced over 3 billion kilograms of grain annually in recent years. Recently, Bayannur has focused on modernizing the irrigation system, implementing water-saving measures, and enhancing ecological management within the Hetao Irrigation Area. In recent years, the Farmland Rights Confirmation Policy and the Circulation (transfer) of Rural Land Contracting and Management Rights started to emerge in Bayannur. It is a notable trend that some companies have started to lease significant amounts of land from small household farmers. Still, it is not widespread yet as unprecedented challenges are also emerging. One of the biggest conflicts is adopting and utilizing digital agricultural technologies. While agricultural practitioners' awareness of digital technologies impacts their application significantly.

In summary, targeting an essential agricultural region in an important agricultural country with an emerging digital agriculture era to investigate agricultural practitioners' perceptions of digital agricultural technologies is obviously an important solution to ensuring food security from a sustainable perspective. Investigating a sample from an enormously populous country to determine individuals' awareness of food safety, food security, and food waste behavior can contribute to education and policy-making to ensure food security from the viewpoint of all global citizens. Nevertheless, it is impossible to carry out research that can represent the entire country of China based on

the topics in this thesis because of the research methods limitation, enormous territory, and imbalanced development in different regions. However, the methods and results can be useful for conducting research on larger populations, and the scientific results can contribute to other researchers' work.

3.3 Data collection

3.3.1 Secondary research review

Firstly, the time-stamped data, literature [106], readily available government websites, thesis, conference presentations, publications, some official surveys based on authorial announcers (official international organizations, such as FAO, the UN, OECD, World Bank, etc.), and other documents available on the internet were utilized to conduct multiple secondary research reviews [107]. To comprehensively understand the paths to ensure food security, Michael E. Porter's value chain theory [108] was used to identify the agriculture and food value chain, and Roger's Diffusion of Innovation Theory (DOI) [109], [110] was utilized to understand the development of sustainable solutions. The secondary research was analyzed by content analysis [111]. A time series analysis was employed to predict the main crop export quantity from the important world food supply countries, Russia, Ukraine [8], [9], [112] , and China.

3.3.2 Questionnaire and sampling method

The self-reported method was commonly employed in food safety and food security awareness research 4.3) to assess individuals' knowledge, attitudes, and practices (KAP). The KAP model, known as knowledge, attitude, and practice, has been used in many studies to survey important food value chain players' knowledge, attitude, and practice [113], [114]. This model employed in the research can help us understand multiple important players' awareness and behavior along the food value chain.

In order to investigate Chinese people's food waste behavior 4.5) and due to the scale of our research ability, the self-reported [115] method was also employed. The self-reported method [116] to design the survey can be valuable for capturing subjective insights that are challenging to measure objectively. These methods provide a direct window into individuals' perceptions, experiences, and attitudes, offering nuanced data that more objective measures might miss.

The questionnaires were designed and distributed through Wen Juan Xing (one of the most popular Chinese online survey platforms) via WeChat (a widely used Chinese social

media platform) after a pilot study conducted in May 2024. Following the pilot study, some questions were modified for clarity and effectiveness, and the questionnaires were conducted from June 2024 to July 2024. Both QR codes and URLs were used to distribute the questionnaire link. In total, 328 participants answered the first questionnaire and 276 in the second questionnaire. Data from the completed questionnaires were entered into a database and analyzed using the statistical software IBM SPSS Statistics 26.

The study sample was selected to approximate the broader Chinese population. Due to the limitation of reaching a representative sample of the entire Chinese population, the sample was obtained using a combination of convenience sampling and snowball sampling methods, which gathered a diverse sample, though it may not fully represent the entire Chinese population. The initial participants were recruited through convenience sampling by sharing the questionnaire via WeChat posts and various WeChat groups. To expand the sample size and enhance diversity, snowball sampling was employed by encouraging friends and family to share the questionnaire with their WeChat contacts. This referral process extended the survey's reach through social networks, bringing in additional participants beyond immediate connections.

3.3.3 Interview

As the literature concluded, the two most important characters, farmers at the production stage and consumers at the consumption stage were identified as the path solutions to ensure sustainable food security. Farmers' role in ensuring food security from the perspective of digital agricultural production was discussed in detail by interview in subchapter 4.4.

3.4 Methodology of case studies

In this section, the specific method of each case study was provided, and the explanation of each method was given in APPENDIX. Statistics analysis.

3.4.1 CS 1. Time series analysis of the main crop export quantity from Russia, Ukraine, and China

A time series analysis of the important world food supply countries, Russia, Ukraine [8], [9], [112], and China [117], [118], [119], in main crop export quantity (wheat, maize, barley, and sunflower seed) during 2010-2021 was conducted in May 2022 amid the ongoing war between Russia and Ukraine. In order to make sure the research results are accurate, the main crop export quantity from these three countries comes from the same

data source, FAOSTAT (Food and Agriculture Organization Corporate Statistical Database) [120]. This research aimed to predict the future world food supply if there was no Russia-Ukraine war from two perspectives: important world food supply countries at war and not at war. Holt-Winters exponential smoothing additive model has been applied [121], [122], [123], [124].

3.4.2 CS 2. Organic food consuming behavior in China and Hungary

A convenient online sampling technique was used to collect the data for the primary research (questionnaire), and the questionnaire was conducted in two languages, Chinese and Hungarian, in 2021. The questions were formulated by taking into consideration numerous literature [77], [88], [92]. Due to the COVID-19 pandemic, the questionnaire promises the available data collection without time, space, and financial limitations. And the data can be easily analyzed as all the respondents see the same questions [125], [126]. Spass software analysis was used to analyze the large data set with different formats from the questionnaire efficiently and adequately [127], [128]

3.4.3 CS 3. Awareness of food safety and food security among different players in the food value chain

Food safety is a significant public health concern. Food security awareness is a crucial area of research focused on understanding how individuals perceive and respond to issues related to food availability, accessibility, utilization, and stability. Understanding different important food value chain players' knowledge, attitudes, and practices can help us to identify gaps in knowledge and practices and then contribute to effective interventions.

3.4.3.1 Questionnaire design

The survey was divided into basic demographic questions (age, gender, living area, highest education, current occupation, monthly income, religion, and food habits), respondents' KAP in food safety and food security, and effective strategies to raise awareness. Their roles across the food value chain were asked as the research aimed to imply the different important food value chain players' food safety and food security awareness. The survey questions were carefully designed based on a foundation of well-established and proven literature, ensuring that they are grounded in reliable research and theory. Meanwhile, some questions were derived from the reality of daily life. The question types included multiple choice, dichotomous, and Likert scale formats, allowing

for a structured and efficient collection of responses. Only the Likert scale was used to design the KAP questions, which allowed the scores to be assigned to evaluate respondents' awareness of food safety.

3.4.3.2 Data analysis technique

Respondents' demographic characteristics and perception of solutions to raise food safety and food security awareness across the food value chain were analyzed by descriptive analysis, such as frequency, percentage, mean value, and standard deviation. Scores for self-reported food safety and food security KAP were determined by assigning points according to the Likert-Scale survey and reported as means, standard deviations, and percentages to make the results easier to interpret. The determinant factor of the five important food value chain players' perception of food safety was examined by correlation analysis (Chi-Square). The cluster analysis was employed to group respondents from food safety and food security awareness, respectively, aimed to classify data points by their underlying similarities, striving to reduce variance within clusters and increase variance between them. Pearson correlation analysis was employed to explore the correlations between food safety and food security awareness by a four-point Likert Scale, avoiding neutral opinion.

3.4.4 CS 4. Farmer's perception of digital agricultural technologies

The semi-structured interview was conducted among "new" and "traditional" agricultural practitioners based on the Technology Acceptance Model (TAM) among agricultural practitioners in Bayannur. The interview questions took into consideration the previous successful research [129], [130], [131], [132]. Some questions may not directly relate to this specific study but are included to ensure thoroughness.

3.4.4.1 Interview design

The interview design consisted of a semi-structured, primarily based on open-ended questions, allowing for in-depth exploration and understanding and diverse respondents' views. According to TAM, external factors, including the specific features of the technology, also play a significant role. These external factors affect both the user's intention to use the technology and their actual usage behavior through key mediating variables, namely perceived usefulness, perceived ease of use, and attitude toward the technology. The main demographic characteristics were asked before the interview. The knowledge about digital agricultural technologies obtained from the interviewed farmers

was identified as the usefulness of using DAT. The following parts were the risk perception of respondents on DAT and the ease of using DAT. In the end, respondents were asked to provide supplementary comments about their understanding of DAT besides the interview questions. After all questions and comments, the interviewee used three words to summarize their perception of DAT.

3.4.4.2 Sample and data collection

Purposive non-probability sampling was selected to explore the agricultural practitioners' perception of DAT in Bayannur for the aim of in-depth understanding and insights into this city rather than representativeness of the entire country. Five agricultural practitioners are involved from diverse backgrounds, such as traditional farmers (farmer couples), new farmers, sunflower seed purchasing and initial processing plant owners in post-harvest processing, and seed sale store owners in the supply chain of agricultural inputs.

The demographic characteristics of the interviewees were given before the interview (Table 2). The traditional farmers represent the common rural land households, which are featured by aging, small-scale lands, and relatively low levels of education (before high school) and facing a massive change brought about by CRLCMR policy. Some lease their lands to big companies, while others still operate on small-scale lands. None of the interviewees have a religion and are non-vegetarian. Mr. Wu, the traditional farmer identified in this research, was born in 1970 and obtained his highest education (middle school) in 1985. When he finished school, his agricultural career started, and it has been 39 years since then. He has the Land Contracting and Management rights for 2.13 ha arable lands, and he has utilized digital agricultural technologies for 15 years since he started using the internet. Mrs. Wu, as Mr. Wu's wife, was born in 1970, and her agricultural career experience is 29 years since she got married. She finished high school in 1991 and then tried different jobs rather than agriculture. As a traditional local household, she has the same characteristics as Mr. Wu in the years of utilizing agricultural technologies, the size of arable lands, and access to the lands due to Land Contracting and Management rights. The couple interviewee represents the typical agricultural household task distribution in Bayannur, where women usually afford more household work, such as cleaning and cooking, and less farming work or decision-making tasks than men in the fields.

Mr. Cui, identified as a “new” farmer, was born in 1997, holds a bachelor's degree obtained in 2019, and resides in the city center. He represents the emerging rural roles who are featured as young born after 1995, obtained a bachelor's or higher degree, obtained their degree in a big city, and then came back to the village for an agriculture career, familiar with digital technologies, such as internet and utilized it into agricultural practice. Usually, they lease large-scale lands from one or more villages for the convenience of modern and mechanized operations. These characteristics are not only adapted to local regions but also can be seen in the current general situation in China. Mr. Cui has leased 100 ha of arable land since 2022 under the CRLCMR policy. DAT has been utilized since he started his agricultural career. He has a rented house near the agricultural fields for his accommodation when working in the agricultural season.

The “new” farmer was defined in the thesis to describe two other influential agricultural practitioners with crucial and typical roles in local agricultural economics, which can be projected to other local agricultural plants and input suppliers. In Bayannur, it is common to encounter small stores or agricultural plants that are family-owned and passed down through generations. For example, Mr. Liu and Mr. Gao completed their higher education before returning to manage their family businesses. Mr. Liu, born in 1997 and obtained his bachelor's degree in 2020, runs a seed sale store from his parents, which is the primary source of seed purchase for local traditional farmers. The seed sale store owners advertise and sell seeds to local farmers directly in the supply chain of agricultural inputs, while they are facing the challenge from the bigger seed companies as they cannot meet the demands of bigger companies with transferred lands rather than small households farmers. After university, he started to run the store and utilized DAT for his business for four years. The size of his private store, 60 m^2, is common to see in other similar local agricultural service stores. He uses the Internet to search for information about climate prediction and crop varieties, buy crop seeds, and then sell them to local individual small-scale land farmers.

Mr. Gao, who operates a private sunflower seed purchasing and initial processing plant, was born in 1995. The sunflower seed plant owner purchases the harvested sunflower seed directly from the local farmers and then sells it domestically or exports it to foreign markets after the initial processing of quality control, such as screening. He finished his college studies in 2014 and started to take over his family’s private business five years

ago, simultaneously implementing DAT in the plant. The size of his plant, 1,000 m², is comparable to that of similar regional agricultural facilities.

Table 2 Interviewees' demographic information, N=5 ($Year_B$=Birth year,$Year_E$=Highest education and obtained year,$Year_A$=Years of agricultural practice, $Year_D$= Years of utilizing DAT)

Name	$Year_B$	$Year_D$	$Year_A$	$Year_D$	Size	Ownership or management rights
Mr. Wu	1970	Middle school, 1985	39	15	2.13 (ha)	Land Contracting and Management
Mr. Cui	1996	BSc, 2019	2	2	100 (ha)	Management Rights under the Land Transfer Policy
Mrs. Wu	1970	High school, 1991	29	15	2.13 (ha)	Land Contracting and Management
Mr. Liu	1997	BSc, 2020	4	4	60 (m^2)	Private
Mr. Gao	1995	College, 2014	5	5	1000 (m^2)	Private

Source: authors' own research

Before each interview, the purpose of the interview and consent to participate were confirmed with the interviewee. A brief introduction to DAT was given to all interviewees before starting the interview questions to make them feel relaxed and confident about the interview. All the interviews were recorded after each interviewee's consent was obtained.

3.4.4.3 Data analysis

All the interview recordings were translated into English and transcribed in the first step. The transcripts were read repeatedly to ensure familiarity with the content. Secondly, a preliminary analysis was conducted to explore the initial codes, and 80 initial codes were identified. In the third step, the transcripts were re-read to refine, merge, and integrate these codes, resulting in 31 secondary codes (Figure 7). In the fourth step, these 31 codes were categorized into potential themes, ultimately resulting in ten overarching themes. Finally, the fifth step involved returning to review the interview transcripts to contextualize the themes.

3.4.5 CS 5. food waste behavior

3.4.5.1 Questionnaire design

To compensate for the limitation of the sampling method, both food waste frequency and food waste amount were investeigated to have more reliable results. This research utilizes a cross-sectional survey methodology [133] to evaluate food waste behaviors among the Chinese population, which facilitates efficient data collection, making it a practical choice for large-scale studies. It offers a comprehensive snapshot of food waste behaviors across diverse segments of the population, enabling a holistic understanding of the issue at a specific point in time. This approach enables the analysis of the prevalence of food waste and the exploration of relationships between various factors that influence food waste behaviors. The survey questions were designed based on a foundation of concrete and

proven literature. Some research verified that ethnicity also has an influence. Therefore, I added this question to respondents. But only two ethnic groups were offered to choose, Han and Minority, as most Chinese people are Han. Only respondents' opinions on lunch and dinner were investigated because the respondents were asked to evaluate their food waste behavior during workdays. So, breakfast is not a significant consideration as a large number of them don't have breakfast or don't eat in the canteen. The questions were shown as closed-ended questions to capture quantitative data and provide respondents with an opportunity to elaborate on their food waste practices easily. The types of questions included multiple choice, dichotomous, and Likert scale.

3.4.5.2 Data analysis techniques

Firstly, Cronbach's Alpha coefficient (α) was employed to assess the internal consistency of a questionnaire. Descriptive statistics were used to summarize the sample's demographic characteristics (such as the frequency, percentage, mean, and standard deviation of demographic variables to explain the prevalence, average level, and degree of variation or consistency of the sample) and the prevalence of different food waste behaviors. Inferential statistics, such as chi-square tests and logistic regression, were employed to examine the relationships between demographic variables and food waste behavior.

Before further analysis, the questionnaire data were cleaned and checked. The correlation analysis between food waste frequency and the possible causes. Spearman's rank correlation coefficients were calculated between the food consumption habits, food waste attitude, knowledge and awareness, and the food waste behavior (frequency and amount) to assess the bivariate relationships between food waste, food consumption habits, food waste attitude, knowledge and awareness.

Ordinal logistic regression analysis was performed between food waste behavior (frequency or amount) and demographic characteristics, attitude, knowledge, and food consumption habits to examine the strength of their relationship as both dependent and independent variables are ordinal or nominal categories. The dependent variables were shown as 5 scale-likert (1 = "never," 2 = "rarely," 3 = "sometimes," 4 = "often," and 5 = "always.") for food waste frequency and 5 scale-likert (1 = "none or tiny," 2 = "some," 3 = "half," 4 = "more than half," and 5 = "most or all.") for the ratio of food waste. The predictors were also scaled from minimum to maximum. When the significant predictors

of the dependent variable through the initial Chi-square and Spearman's rank correlation analysis were included in the ordinal logistic regression model, where the dependent variable is food waste frequency, the test of parallel lines indicated a violation of the proportional odds assumption. To address this issue, the model was expanded to include all predictors, which resulted in the proportional odds assumption being satisfied and the model demonstrating a good fit. When the "food waste amount" used in the questionnaire was tested as the dependent variable, the same issue happened. However, the problem can be solved when the "ratio of food waste" is replaced as the dependent variable. Therefore, the model was expanded and adjusted to all predictors to test the determinants of food waste behavior, which was demonstrated as food waste frequency and food waste ratio. This comprehensive approach enables us to capture the complex interactions among the variables more effectively.

In order to reveal the links between sociodemographics, food consumption habits, and attitudes regarding food waste behavior, cluster analysis was employed to segment the dataset into meaningful groups.

In the first part of the survey, respondents were asked to choose their dining habits from two options (purchasing food from the university/company cafeteria or cooking meals at home/dormitory) and complete the survey according to their chosen dining habits. A decision tree analysis was employed to reveal the association between different dining habits regarding food waste behavior.

At the end of the survey, providing some effective food waste reduction strategies to the public and individuals is one of the aims. The effectiveness of various strategies to reduce food waste was evaluated using a 5-point Likert scale ranging from '1. not important' to ' 5. very important,' with the intermediate points being '2. less important', '3. neutral', and '4. somehow important. This scale allows quantitatively measuring the varying degrees of importance participants attributed to each factor. The percentage of respondents' opinions on each strategy, mean, and standard deviation were analyzed. Percentages for each importance level (1 to 5) provide a detailed breakdown of respondents' opinions, showing the actual distribution of responses. This granular data helps in understanding the distribution of ratings across different strategies. It can help to identify specific trends, such as whether a strategy is polarized, with many high and low ratings, or generally agreed upon, with most ratings in the middle. By providing percentages, how each

strategy is rated can be directly compared. This makes it easier to identify which strategies are perceived as more important by the majority and which ones are less favored. The detailed percentages allow for a more nuanced analysis, enabling better-informed decisions based on the varied perceptions of respondents. The mean provides a single value that summarizes the central point of respondents' opinion, indicating how respondents, on average, evaluated the food waste reduction strategies. This allows for easy comparison between different strategies or groups to identify which is perceived as the most effective. The standard deviation indicates the variability or dispersion of the responses around the mean. Understanding this spread helps interpret how consistently respondents rated each strategy, giving more context to the average ratings.

4 RESULTS

Following the design of the thesis, the results of multiple case studies and secondary research studies were explained in this chapter. A summary of scientific results of each case study was provided (Table 3). In this chapter, each subchapter was named after the topic, which was supported by the case study and secondary research. Only the main results of each study were given due to the page limit.

Table 3 The new scientific results of each case study

No.	Case study	Results
1	Time series analysis of the main crop export quantity from Russia, Ukraine, and China	Russia and Ukraine will be crucial world food suppliers for main crop products, such as wheat, maize, barley, and sunflower seeds. Unfortunately, these two important world food supply countries are still in a long-term conflict, pushing global food security into a worse situation. China will also play an important role in the world's sunflower seed supply for the world.
2	Organic food consuming behavior in China and Hungary	Chinese respondents (largely from Inner Mongolia) and Hungarian respondents (mostly from Budapest) prioritize food safety, health, and eco-friendliness when buying organic food. Chinese respondents' organic food enthusiasm is less than Hungarian but also high. The main information source for both of them are are social media and advertisements.
3	Awareness of food safety and food security among different players in the food value chain	Awareness of five main important players in food value chain on food safety and food secrutiy are interrelated. There is a significant gap between respondents' awareness and behavior. The government intervention and early education are rated as the most important solutions to raise awareness of food safety and food security.
4	Farmer's perception of digital agricultural technologies	The adoption of DAT in Bayannur is in the early stage, and the adoption level differenciate between traditional and new farmers, but both of them have proactive attitude. The biggest barrier to adopt DAT in Bayannur is aging workforce and small-scale of lands. The most efficient solution to improve the faciliating of DAT is govermental intervention and the most efficient solution to strenthen awareness of DAT, food waste and food security is early eduction.
5	Food waste behavior	Food waste is quite a common issue in China, which is imacted by demographic characteristics, consumption habits, food waste awareness, knowledge and attitude. But resondents believe behavioral-change intervention and infrastructural interventions can efficiently reduce food waste.

Source: author's own construction, $N_{CS\ 2.}$=581 (2021), $N_{CS\ 3.}$=328 (2024), $N_{CS\ 4.}$=5 (2024), $N_{CS\ 5.}$=276 (2024)

4.1 Food security crisis (Result of CS 1. Time series analysis of the main crop export quantity from Russia, Ukraine, and China)

4.1.1 Results of CS. 1 about main crop export quantity prediction

In the CS. 1 [134], the time series data on the main crop export quantity was collected from the 2010-2021 trend data from Ukraine, Russia, and China, including wheat, maize, barley, and sunflower seeds. The time series data analysis has been carried out in every case, and the result is demonstrated for the forecasting period 2022-2024. Due to the importance of this research for the entire thesis and the page limit, only the example of wheat export quantity prediction (Table 4, Figure 2) and the main results were given.

In Ukraine, the wheat and maize export quantity is expected to increase yearly, while the barley and sunflower seed export quantity is projected to decrease for 2022-2024. But the amount after decreasing is still high. Other experts projected that the Ukraine maize export in 2022/23 will be 23.5 million tons [135], while our model shows 25 million tons. Russia will still play an important role in the world food supply, especially in the world wheat, barley, and sunflower seed supply. The model in this research predicted in the year 2022-2024, the wheat, maize, barley, and sunflower seed export quantity in Russia would keep increasing. Some experts predicted the export of wheat in Russia in 2022/23 will be between 200 thousand to 43 million tons [136], making Russia the largest wheat export country [137], and our model shows a similar number, 30 million tons. The Russian sunflower seeds export quantity is estimated to reach 800 thousand tons [138], which is higher than our model estimation of 200 thousand tons. In addition to the dominant world food suppliers, Russia and Ukraine, other huge agricultural countries, such as China, are also crucial. During the period 2022-2024, the role of China is predicted to be important still for the world food supply from the aspects of wheat, maize, barley, and sunflower seed. The wheat, maize, and barley export quantity is projected to decrease steadily, but the sunflower seed export quantity will increase. It means that China's role is not as significant as Russia and Ukraine to the world food supply regarding wheat, maize, and barley, but Chinese sunflower seed export is crucial to the world.

Table 4 Food Forecasting results of wheat export quantity for 2022-2024 in Russia, Ukraine, and China (tons)

Year		2022	2023	2024
Country	Russia	29339606	30171704	31003802
	Ukraine	16373389	13901207	18055673
	China	4281	4515	4749

Source: author's own construction

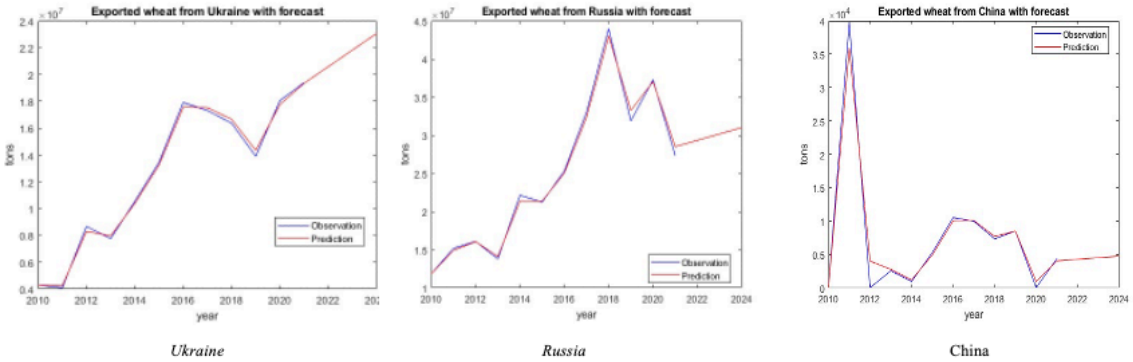

Figure 2 Observed and fitted data series on wheat export quantity in Ukraine, Russia, and China
Source: author's own construction

In summary, Russia and Ukraine will be crucial world food suppliers for main crop products, such as wheat, maize, barley, and sunflower seeds. Unfortunately, these two

important world food supply countries are still in a long-term conflict, pushing global food security into a worse situation. China will also play an important role in the world's sunflower seed supply for the world.

4.1.2 Findings from secondary research

The global security changes and trends are not limited to post-cold War security characteristics, globalization, the 9/11 aftermath, the proliferation of weapons of mass destruction, demographics and security, international organizational crime, natural risks, and health security, international system of governments and modern military capability characteristics from the book “The five central pillars of European security” in 2007 [48], but also included environmental security and biodiversity reduction, global energy market trends, and infrastructure security so far. Meanwhile, it should not be neglected that the positive influence of global warming in the Arctic can shorten the supply chain of goods. Demographic security is one of the most important elements of national security and serves as a central connection to other elements of national security [139].

In the light of the global view, most agricultural risks and threats trends are related to it [140]. The risks and threats in agriculture and food were summarized in Table 5 and the identified risks and threats in agriculture according to different value chain steps were given in Table 6. The nexus between global security changes and risks and trends in agriculture can be seen in the summarized figure (Figure 3). There are many meeting points between global security changes and trends, such as globalization, demographics and security, natural risks, and health security (limit of resources), international system of governments, environmental security and biodiversity (climate change or extreme weather), energy and infrastructure security. Additionally, the future agricultural production and demand, obstacles to irresistible digital agriculture, security issues in agriculture 4.0, market fluctuations and food security issues (food loss and waste) are also under agricultural risks and threats trend.

Table 5 The risks and threats in agriculture and food

Risks and threats in agriculture and food	Other threats to agriculture and food, but not trend
Declining production and increasing demand	COVID-19
Climate change or extreme weather	Russia-Ukraine war
Limit of resources	
Obstacles of the irresistible trend of digital agriculture	
Security issues in agriculture 4.0	
Agricultural commodities market fluctuations	
Food loss and waste	

Source: Own construction

Table 6 The summary of risks and threats in agriculture in different value chain steps

Agriculture and food value chain	Risks and threats						
Agriculture production	Future production and demand	Climate change	Limit resources	Digital agriculture obstacles	Digital security issues	Market fluctuation	Food loss and waste
Food processing	Future production and demand		Limit resources	Digital agriculture obstacles	Digital security issues	Market fluctuation	Food loss and waste
Distribution	Future production and demand	Climate change	Limit resources				Food loss and waste
Retail and food service	Future production and demand		Limit resources			Market fluctuation	Food loss and waste
Consumption	Future production and demand					Market fluctuation	Food loss and waste

Source: Own construction

Figure 3 The risks and threats in agriculture and food in the face of global security changes and trends
Source: Own construction

China has a rich water resource, but the per capita possession is scarce, and water resource use is facing ever-increasing challenges in the agricultural sector in China (for example, the pricing system is insufficient, water waste is vigorous, and the water efficiency is only 54.2% in agricultural irrigation due to the less knowledge of water-saving and undeveloped agriculture irrigation and drainage technology). Fortunately, China has been taking a series of feasible solutions and got positive feedback on water-saving and water conservation and the efficiency and profit of water use increased [141].

The Russia-Ukraine war is the added fuel for buring food security crisis, which negatively impacts food security from the crucial stages causing food crisis (production, processing and logistics), such as cultivation and harvesting interruption, the supply chain changes, farmers' financial issues or producer challenges, infrastructure and price volatility [142].

4.2 The necessity of sustainability (Result of CS 2. Organic food consuming behavior in China and Hungary)

4.2.1 Results of CS. 2 about consuming behavior of organic food

In case study 2 [143], which was about the behavior of consumers of organic food in China and Hungary, the respondents from Hungary (207) mainly lived in the capital city, Budapest. Among the 374 respondents living in China, most of them are from a developing region, Inner Mongolia (55.34%), and some from developed provinces, like Bei Jing, Shang Hai, Guang Dong, etc., 69 (18.45%).

In both China and Hungary, the main factors influencing the purchase of organic food are food safety and health and environmentally friendly. The high price of organic food is crucial for refusing organic food. Chinese respondents do not have the same channel difficulties compared to Hungarian respondents in buying organic food, mainly because the e-commerce industry in China is very popular, and more developed than in Hungary. Hungarian respondents consider income less than Chinese respondents do. Organic fruits and organic vegetables are the most welcomed products in Hungary and China. From the data about current or ideal monthly expenditure (Euros) on organic food, it is concluded that Hungarian respondents prefer to spend more on organic food every month than Chinese respondents. Compared to Chinese respondents, Hungarian respondents like to buy organic food more than Chinese respondents, and Hungarian respondents buy organic food more often than Chinese respondents.

This survey has six information resources or marketing tools for buying organic food products [97]. The main information sources for both Chinese and Hungarian respondents are social media and advertisements. However, Chinese respondents also get information from advertisements from the market, shopkeepers, or retailers. While, Hungarian respondents also obtain information from family, friends, and relatives.

4.2.2 Findings from secondary research

The advanced digital technologies used in agriculture benefit the most SDGs during the whole agrifood value chain, adapt and mitigate climate changes, increase the crop and animal husbandry production while reducing the cost and environmental damage, and boost agicultural economic by increasing efficiency and product quality.

Sustainable agriculture is the only way to feed the future generations due to agriculture is one of the important sectors of national security and exposed to diverse global security risks and threats trend and the agricultural vulnarabilities [144], [145].

As people are becoming more aware of the importance of maintaining adequate nutrition and sustainable consuming habits after COVID-19, meanwhile food security is at risk, agricultural activities workforce is at shortage, food supply chain restrictions are more strict (eg. higiene process) due to COVID-19 and more vigorous food insecurity due to Russia-Ukraine war, the role of intelligent technologies in food supply chain promises the sustainable future [146].

Nevertheless, COVID-19 is a challenge for Chinese agriculture, but it also has some opportunities to change its traditional agriculture system to a modern smart and sustainable agriculture system. China has taken continuous policies accordingly to respond to the demand and supply changes, such as the Minimum Purchase Price Policy, Rural Revitalization Strategy, establishment of construction projects of cold chain logistics facilities for agricultural product storage and preservation, and so on [147].

Conducting a survey on players' awareness of food safety and security in the food value chain is essential for maintaining and improving these aspects, ensuring regulatory compliance, enhancing efficiency, reducing waste, increasing consumer trust, addressing global challenges, fostering innovation, and expanding education and training. Our research focuses on farmers' awareness at the production stage, which is key for managing risks, improving food safety and quality, and enhancing public health and food security.

Raising awareness through education, government interventions, civil society activities, and training for media, influencers, scientific staff, and individuals is vital.

Food production is the base of food security and, food safety, sustainable development infrastructure. Agriculture 3.0 or green agriculture, precision agriculture is a sustainable agriculture system utilizing a series of advanced technologies or machinery in agriculture production, such as information technologies, satellites, remote sensing, drones, IoT, big data, GIS, GPS, etc, which can efficiently promise sustainable agriculture by optimizing the input of agriculture (such as seeds, pesticides, herbicides, agrochemicals, and water), and managing the inputs in the right place at the right time with the right amount, reducing the environmental impact and saving natural resources and boosting the opportunities for production and economic benefits [148].

4.3 The crucial role of education in increasing global citizens' awareness to ensure sustainable food security (Results of CS 3. Awareness of food safety and food security among different players in the food value chain)

The survey has excellent internal consistency in describing food safety and food security awareness self-evaluation, with a Cronbach's α value of 0.912.

4.3.1 Demographic analysis

The demographic analysis of 328 respondents was explained by frequency and percentage (Figure 4). The demographic characteristics are age, gender, living area, highest education, current occupation, monthly income, religion, food habit, and their roles across the food value chain. The sample is predominantly youthful, with a significant portion of respondents aged 21-30 (33.5%) and 31-40 (21.6%). Females comprise 68.3%, and most respondents are from urban areas (81.1%). The educational background of the sample is notably high, with 36.6% holding a Bachelor's degree and 28.7% having a Master's degree. Professionally, nearly half of the respondents are employed (48.5%), while 19.2% are students, and 10.1% are self-employed. Regarding income, a substantial proportion of the sample (40.2%) earns over 6000 yuan monthly, although 29.6% earn less than 4000 yuan. Most respondents do not follow any religion (91.5%) and are predominantly nonvegetarian (95.1%). Most participants identified as consumers in the food value chain (85.1%), with far fewer representing roles such as farmers (26, 7.9%), transporters (7, 2.1%), processors (9, 2.7%), or retailers (7, 2.1%).

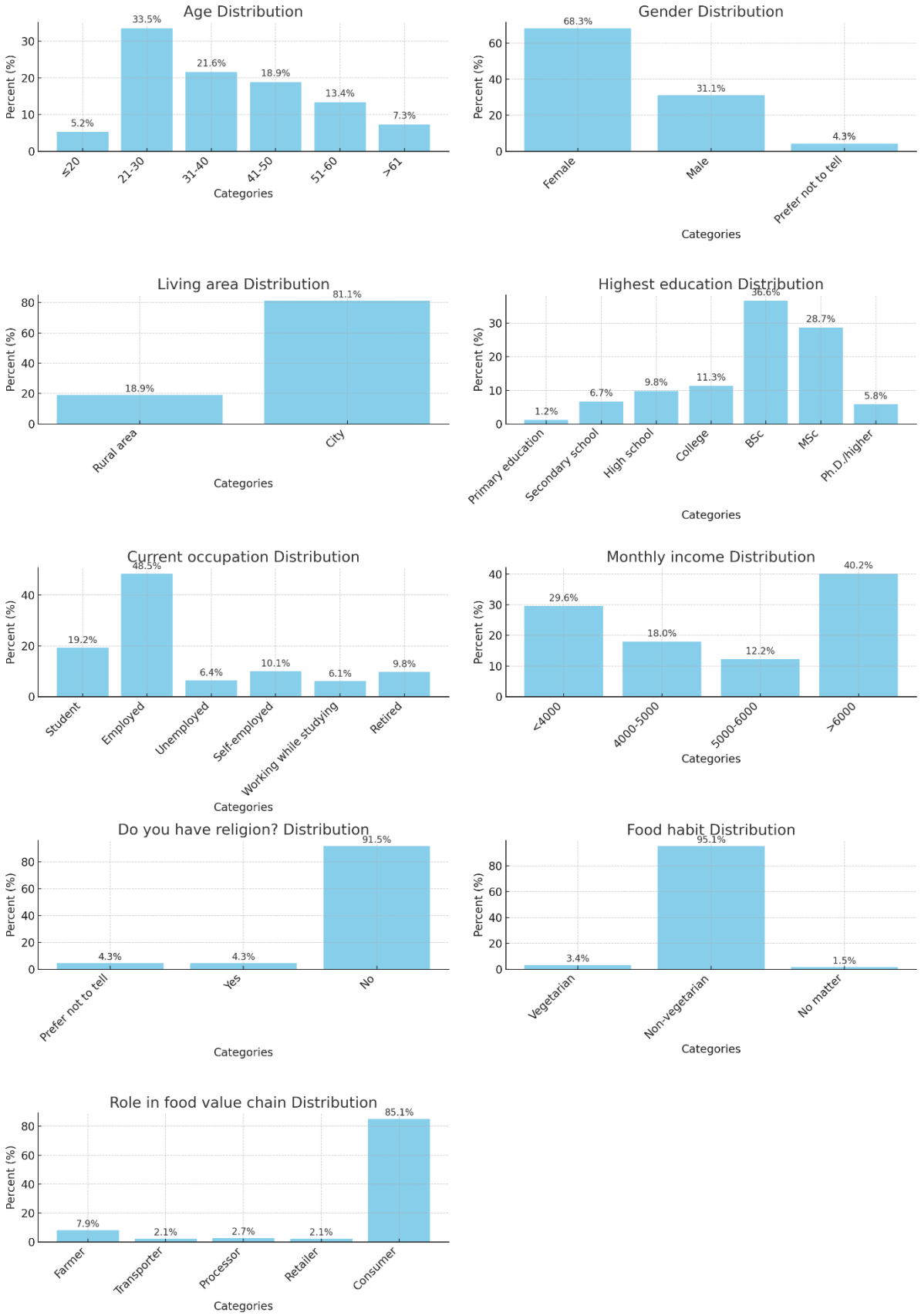

Figure 4 Demographic analysis, N=328
Source: authors' own construction

In summary, the sample reveals a relatively young, urban, and well-educated population, with a predominance of female and good-salary respondents. The income distribution and occupational roles suggest diversity in economic status and professional engagement.

4.3.2 Correlation analysis between the awareness of food safety and food security

The correlation between food safety and food security awareness was examined by Pearson correlation analysis (Table 7). The relationship between respondents' food safety and food security awareness is unlikely to have occurred by chance as all p-values are 0.000, meaning the correlations are highly significant. When respondents were asked to evaluate their understanding of food safety and food security concepts, their correlation was 0.516, with a p-value of 0.000. This indicates a moderate, statistically significant positive relationship. It means that individuals who think they are more familiar with food security concepts are also likely to be more familiar with food safety definitions. Similar results can be found from their perception of these two concepts defined by WHO and FAO. These results suggested that individuals knowledgeable about food security tend also to be knowledgeable about food safety, indicating that awareness in these areas may be interrelated. This could imply that efforts to improve education or awareness in one area (e.g., food security) may also enhance understanding in the other (e.g., food safety).

Table 7 Pearson correlation analysis among food safety and food security awareness, N=328

		1.	2.	3.	4.
1. Familiarity with food safety definition	Pearson Correlation	1			
	Sig. (2-tailed)	-			
2. Familiarity with WHO food safety definition	Pearson Correlation	.571**	1		
	Sig. (2-tailed)	0.000	-		
3. Familiarity with the concept of food security	Pearson Correlation	.516**	.513**	1	
	Sig. (2-tailed)	0.000	0.000	-	
4. Familiarity with FAO's food security definition	Pearson Correlation	.375**	.476**	.679**	1
	Sig. (2-tailed)	0.000	0.000	0.000	-

Source: authors' own construction

4.3.3 KAP reports of food safety awareness

To deeply understand respondents' awareness of food safety, the descriptive analysis of the KAP self-evaluation report was explained (Table 8). Respondents were asked to evaluate their perception of basic food safety knowledge and attitude by a 4-point Likert-Scale and food safety practices by a 6-point Likert-Scale.

Table 8 Food safety KAP evaluation, N=328

KAP	Perception	Frequency (Percentage)	Mean	Std. Deviation
Familiarity with food safety definition	Not at all	77 (23.5%)	1.85	0.574
	Slightly	228 (69.5%)		
	Very	18 (5.5%)		
	Extremely	5 (1.5%)		
Familiarity with WHO food safety definition	Not at all	175 (53.4%)	1.53	0.635
	Slightly	136 (41.5%)		
	Very	13 (4.0%)		
	Extremely	4 (1.2%)		
Familiarity with fact that foodborne illness can cause death	Not at all	132 (40.2%)	1.72	0.721
	Slightly	166 (50.6%)		
	Very	19 (5.8%)		
	Extremely	11 (3.4%)		
Agreement on impact of food storage conditions	Not at all	20 (6.1%)	2.82	0.833
	Slightly	89 (27.1%)		
	Very	150 (45.7%)		
	Extremely	69 (21.0%)		
Agreement on importance of cleaning cooking areas/tools	Not at all	9 (2.7%)	3.18	0.759
	Slightly	43 (13.1%)		
	Very	156 (47.6%)		
	Extremely	120 (36.6%)		
Confidence in ensuring food safety when preparing food	Not at all	16 (4.9%)	2.49	0.686
	Slightly	154 (47.0%)		
	Very	138 (42.1%)		
	Extremely	20 (6.1%)		
Perception of responsibility - Farmers	Not at all	45 (13.7%)	2.59	0.976
	Slightly	115 (35.1%)		
	Very	97 (29.6%)		
	Extremely	71 (21.6%)		
Perception of responsibility - Transporters	Not at all	30 (9.1%)	2.66	0.904
	Slightly	117 (35.7%)		
	Very	114 (34.8%)		
	Extremely	67 (20.4%)		
Perception of responsibility - Processors	Not at all	20 (6.1%)	3.35	0.836
	Slightly	17 (5.2%)		
	Very	119 (36.3%)		
	Extremely	172 (52.4%)		
Perception of responsibility - Food service staff	Not at all	19 (5.8%)	3.13	0.882
	Slightly	51 (15.5%)		
	Very	125 (38.1%)		
	Extremely	133 (40.5%)		
Perception of responsibility - Consumers	Not at all	77 (23.5%)	2.33	1.02
	Slightly	123 (37.5%)		
	Very	71 (21.6%)		
	Extremely	57 (17.4%)		
Hand washing before preparing food	Never	2 (0.6%)	5.04	1.13
	Rarely	6 (1.8%)		
	Sometimes	18 (5.5%)		
	Often	92 (28.0%)		
	Very often	42 (12.8%)		
	Always	168 (51.2%)		
Checking shelf life	Never	4 (1.2%)	4.46	1.324
	Rarely	27 (8.2%)		
	Sometimes	35 (10.7%)		
	Often	117 (35.7%)		
	Very often	39 (11.9%)		
	Always	106 (32.3%)		

Table 8 Food safety KAP evaluation, N=328 (continued)

KAP	Perception	Frequency (Percentage)	Mean	Std. Deviation
Consuming food after expiration date	Never	166 (50.6%)	1.7	0.855
	Rarely	109 (33.2%)		
	Sometimes	42 (12.8%)		
	Often	9 (2.7%)		
	Very often	1 (0.3%)		
	Always	1 (0.3%)		
Throwing away food after expiration date	Never	5 (1.5%)	3.86	1.43
	Rarely	64 (19.5%)		
	Sometimes	68 (20.7%)		
	Often	98 (29.9%)		
	Very often	22 (6.7%)		
	Always	71 (21.6%)		
Cleaning surfaces/utensils after handling raw meat	Never	5 (1.5%)	4.76	1.302
	Rarely	16 (4.9%)		
	Sometimes	25 (7.6%)		
	Often	105 (32.0%)		
	Very often	33 (10.1%)		
	Always	144 (43.9%)		

Source: authors' own construction

In summary, respondents lack food safety knowledge, as proved by the low level of food safety perception (69.5% being only slightly familiar with the general definition of food safety, while 23.5% were not familiar at all. The mean was relatively low at 1.85, with a standard deviation of 0.574), international food safety standards (the mean score of WHO definition perception was 1.53 with SD of 0.635), and foodborne illness awareness (50.6% of respondents were slightly aware with a mean score of 1.72 and SD of 0.721). It should be maintained and improved in their attitude because of the moderate level of knowing the impact of proper food storage conditions (mean score of 2.82 and SD of 0.833), confidence in ensuring food safety while preparing food (47.0% slightly confident and 42.1% very confident with mean score of 2.49 and SD of 0.686), and a little bit higher than moderate level of the importance of cleaning cooking areas and tools (high mean score of 3.18 and SD of 0.759).

Even though the respondents are not aware of food safety knowledge well, they have good practices in food safety in their daily lives, as relatively higher levels of food safety practices, such as hand washing before food preparation (51.2% always practicing it, reflected in a mean score of 5.04 and SD of 1.13), checking food shelf life, being cautious about consuming expired food (50.6% of respondents reported never doing so, yet 33.2% admitted to rarely checking expiration dates with a low mean score of 1.7 and SD of 0.855), throwing away expired food (mean score of 3.86 and SD of 1.43) and cleaning surfaces or utensils after handling raw meat (43.9% of respondents always clean surfaces or utensils after handling raw meat with a mean score of 4.76 and SD of 1.302). Besides

the five important food value chain players' food safety KAP evaluation, they also think that food processors (mean = 3.35, SD = 0.836) and food service staff (mean = 3.13, SD = 0.882) are the most responsible roles for food safety across the food value chain, instead of farmers, transporters, and consumers. Efforts to enhance food safety knowledge should be prioritized to ensure good practices are maintained and supported by a solid understanding of food safety issues.

4.3.4 Determinants of food safety awareness level

In order to explore the factors that determine or influence the five important food value chain players' perception of food safety defined by WHO as "unsafe food containing harmful bacteria, viruses, parasites or chemicals can cause more than 200 different diseases, from diarrhea to cancer", a Chi-Square was employed and it was evaluated by six points Likert Scale from "not familiar at all" to "extremely familiar". The result is demonstrated as a Chi-Square analysis (Table 9). As the Chi-Square analysis table revealed, the socio-demographic characteristics were set as variables to explain their influence on the perception of food safety. There is no statistically significant relationship between age (χ^2=21.927, p=0.11), gender (χ^2=3.854, p=0.696), living area (χ^2=2.174, p=0.537), and perception of food safety at the conventional significance level. The variable for the highest degree (χ^2=28.867, p=0.05) obtained is on the borderline of statistical significance, suggesting that education level may have a marginal effect on food safety perceptions. Current occupation (χ^2=26.233, p=0.036), monthly income (χ^2=17.791, p=0.038), religion (χ^2=24.795, p=0.000), and role in the food value chain (χ^2=51.68, p=0.000) indicated a statistically significant relationship between with food safety perception respectively. Food habits (χ^2=77.065 p=0.000) had the strongest association with food safety perception.

Table 9 Chi-Square analysis of respondents perception of food safety defined by WHO, N=328

	Variables	Pearson Chi-Square	Degrees of Freedom (df)	P-Value
Perception of food safety	Age	21.927	15	0.11
	Gender	3.854	6	0.696
	Living area	2.174	3	0.537
	Highest degree	28.867	18	0.05
	Current occupation	26.233	15	0.036
	Monthly income	17.791	9	0.038
	Religion	24.795	6	0.000
	Food habit	77.065	6	0.000
	Food value chain role	51.68	12	0.000

Source: authors' own construction

Overall, Chinese current occupation, monthly income, religion, food habit, and their role in the food value chain significantly affect their perception of food safety. Their education may have a marginal impact on how individuals perceive food safety, but the result is right on the threshold of significance. Meanwhile, respondents' age, gender, and living area do not impact their perception of food safety.

4.3.5 Cluster analysis of food safety awareness

Cluster analysis was used to explore the number of clusters formed from different important food value chain players' KAP of food safety, and two significantly different clusters were given (Table 10). According to respondents' different performances in food safety KAP, they were properly grouped into two groups as captured by their z-scores across various variables, 162 in cluster 1 and 166 in cluster 2.

Cluster 1 exhibited positive z-scores across most variables, indicating a higher-than-average familiarity and agreement with food safety concepts and behavior with food safety practices. For example, respondents in this cluster showed a better self-evaluation of food safety perception (z=0.2926), a strong familiarity of the food safety concept defined by WHO (z=0.20486), a strong agreement with the fact that foodborne illness can cause death (z=0.29939), with the importance of food storage conditions (z=0.36771), and with the importance of cleaning cooking areas/tools (z=0.45429). This group also showed a strong confidence in ensuring food safety when preparing food (z=0.25176) and a pronounced perception of responsibility among all five important food value chain players, including farmers (z=0.55161), transporters (z=0.58279), processors (z=0.48128), and food service staff (z=0.53408). In food safety practice, this group also demonstrated proactive food safety behaviors, such as regular handwashing before food preparation (z=0.36107), regular checking shelf life (z=0.40982), less often consuming the expired food (z=-0.07293), more often throwing away expired food (z=0.20387), and cleaning surfaces/utensils after handling raw meat (z=0.43166). Concerning good food safety perception and practice, this group can be named "food safety-conscious."

In contrast, cluster 2 displayed predominantly negative z-scores, suggesting a lower-than-average engagement with food safety beliefs and practices. Members of this cluster were less familiar and agreed with food safety definitions and guidelines, as evidenced by negative z-scores in food safety definitions self-evaluation (z=−0.28555), familiarity with the WHO food safety definition (z=−0.19992), agreement with the fact that foodborne

illness can cause death (z=-0.29218), with the importance of food storage conditions (z=-0.35885), and with the importance of cleaning cooking areas/tools (z=-0.44334). The group has a weak confidence in ensuring food safety when preparing food (z=-0.24569) and an uncertain perception of responsibility among all five important food value chain players. Moreover, they showed not as good as the first group in food safety practices, such as irregular handwashing before food preparation (z=-0.35237), irregular checking shelf life (z=-0.39994), more often consuming expired food (z=0.07118), less often throwing away expired food (z=-0.19896), and irregular cleaning surfaces/utensils after handling raw meat (z=-0.42126). In comparison to the first group, this group can be named "food safety-unaware."

Table 10 Final cluster analysis of respondents' food safety knowledge, attitudes, and practice, N=328

Variable	Cluster 1 (49% (N=162))	Cluster 2 (51% (N=166))
Familiarity with food safety definition	0.2926	-0.28555
Familiarity with WHO food safety definition	0.20486	-0.19992
Familiarity with fact that foodborne illness can cause death	0.29939	-0.29218
Agreement on impact of food storage conditions	0.36771	-0.35885
Agreement on importance of cleaning cooking areas/tools	0.45429	-0.44334
Confidence in ensuring food safety when preparing food	0.25176	-0.24569
Perception of responsibility - Farmers	0.55161	-0.53832
- Transporters	0.58279	-0.56875
- Processors	0.48128	-0.46969
- Food service staff	0.53408	-0.52121
- Consumers	0.53636	-0.52344
Hand washing before preparing food	0.36107	-0.35237
Checking shelf life	0.40982	-0.39994
Consuming food after expiration date	-0.07293	0.07118
Throwing away food after expiration date	0.20387	-0.19896
Cleaning surfaces/utensils after handling raw meat	0.43166	-0.42126

Source: authors' own construction

Besides the most distinct variables from two food safety KAP groups, one of the food safety practices did not a too significant difference, as evidenced by a small z-score in the frequency of consuming expired food (Group 1: z=-0.07293 and Group 2: z=0.07118). To ensure the results obtained from K-means cluster analysis, ANOVA analysis on the obtained cluster was performed to validate the effectiveness of the cluster results (Table 11). The Sig. (p-value) for most variables is 0.000, indicating that the differences between clusters are statistically significant at the 0.05 level ($p < 0.05$). Only "Throwing away food after expiration date" (p=0.192) has no significant difference between the clusters regarding this behavior. The significant F-values across most variables suggest that the clusters represent groups with markedly different levels of familiarity, agreement, and behavior regarding food safety practices.

Table 11 ANOVA analysis of respondents' food safety KAP, N=328

	Cluster		F	Sig.
	Mean Square	df		
Familiarity with food safety definition	27.406	1	29.821	0.000
Familiarity with WHO food safety definition	13.433	1	13.966	0.000
Familiarity with fact that foodborne illness can cause death	28.692	1	31.355	0.000
Agreement on impact of food storage conditions	43.280	1	49.730	0.000
Agreement on importance of cleaning cooking areas/tools	66.061	1	82.532	0.000
Confidence in ensuring food safety when preparing food	20.288	1	21.564	0.000
Perception of responsibility - Farmers	97.397	1	138.287	0.000
- Transporters	108.719	1	162.370	0.000
- Processors	74.145	1	95.593	0.000
- Food service staff	91.303	1	126.284	0.000
- Consumers	92.087	1	127.794	0.000
Hand washing before preparing food	41.731	1	47.689	0.000
Checking shelf life	53.760	1	64.141	0.000
Consuming food after expiration date	1.703	1	1.706	0.192
Throwing away food after expiration date	13.304	1	13.826	0.000
Cleaning surfaces/utensils after handling raw meat	59.644	1	72.727	0.000

Source: authors' own construction

After obtaining the proper clusters and validating their reality, the socio-demographic characteristics of each cluster were summarized, such as age, gender, living area, education, current occupation, monthly income, religion, food habits, and role in the food value chain. The Chi-Square test validated their significance (Table 12).

Table 12 Socio-demographic characteristics among clusters, N=328

		Cluster Number of Case		Chi-Square Tests		
		1	2	Pearson Chi-Square	df	Sig.
1. Age:	⩽20	6	11	4.879	5	0.431
	21-30	48	62			
	31-40	39	32			
	41-50	31	31			
	51-60	25	19			
	>61	13	11			
2. Gender:	female	110	114	.023	2	0.989
	male	51	51			
	prefer not to tell	1	1			
3. Living area:	rural area	27	35	1.044	1	0.307
	city	135	131			
4. Highest education:	primary education	1	3	4.726	6	0.579
	secondary school	11	11			
	high school	18	14			
	college	15	22			
	BSc	65	55			
	MSc	42	52			
	Ph.D./higher	10	9			
5. Current occupation:	student	22	41	9.002	5	0.109
	employed	88	71			
	unemployed	9	12			
	self-employed	15	18			
	working while studying	12	8			
	retired	16	16			
6. Monthly income?	<4000	42	55	2.468	3	0.481
	4000-5000	29	30			
	5000-6000	20	20			
	>6000	71	61			
7. Do you have religion?	yes	8	6	.576	2	0.750
	no	148	152			
	prefer not to tell	6	8			
8. Food habit:	non-vegetarian	156	156	2.424	2	0.298
	vegetarian	3	8			
	no matter	3	2			
9. Define your role in food value chain	farmer	13	13	3.613	4	0.461
	transporter	2	5			
	processor	3	6			
	retailer	2	5			
	consumer	142	137			

Source: authors' own construction

Generally speaking, Cluster 1 is formed by relatively older members who live in the city, are employed, have better salaries, and have higher degrees. Vice versa, in Cluster 2, members are more likely younger students with lower salaries and lower degrees. Even though there are no significantly different socio-demographic characteristics among clusters, practical strategies to raise food safety awareness can be given according to different groups.

4.3.6 KAP reports of food security awareness

The following section presents the descriptive analysis of the KAP survey on food security among respondents. The analysis focuses on key areas such as familiarity with food security concepts, perceptions of food security issues, attitudes toward responsibility within the food value chain, and actual food security practices. The statistics analysis process can be seen in subchapter 4.3.3 about the KAP report on food safety awareness, and only the main results were given in this section.

Respondents have a complicated picture of food security knowledge, attitudes, and practices. The analysis of respondents' familiarity with food security concepts reveals a significant gap in knowledge. The level of understanding of food security definition (a majority of respondents (60.1%) were only slightly familiar with the concept of food security, and 26.8% indicated that they are not familiar at all. M=1.91, SD = 0.741) and international standards (38.7% not familiar and only 4.6% extremely familiar. M=1.77, SD = 0.763) are low. These findings suggest a need for increased education and awareness regarding fundamental food security concepts.

The impact of COVID-19 and ongoing wars, such as the Russian-Ukrainian and Israel-Palestine conflicts, were perceived with slightly lower urgency (M=2.43, SD = 0.909; M=2.43, SD = 1.059). The moderate level can be seen from the impact of various risks on food security (natural risks: M=2.63, SD=0.9; climate change: M=2.59, SD=0.82; economic instability: M=2.54, SD=0.819; insufficient agriculture policy: M=2.62, SD=0.807; poor infrastructure: M=2.63, SD=0.783), awareness of the importance of digital agriculture in ensuring food security (M=2.38, SD=0.799), and confidence in their practices in contributing to food security (M=2.17, SD=0.788). The moderate to high level of agreement is on the importance of awareness in ensuring food security (M=3.08, SD = 0.756), challenges to food security (lack of natural resources: M=2.77, SD=0.893; lack of knowledge or education: M=2.83, SD=0.811; and the country's GDP: M=2.61, SD=0.783) and the effect of collaboration and communication among important food value chain players to ensure food security (M=2.86 (SD=0.777). Policy and regulatory barriers were rated as the biggest threat, with the highest mean value of 3.01 (SD=0.88) compared to other challenges threatening food security in their region. Respondents tended to assign higher responsibility to food processors (M=3.19, SD=0.843) and food service staff (M=3.03, SD=0.891) when evaluating the responsible role for food security. At the same time, farmers (M=2.66, SD=0.919), transporters (M=2.69, SD=0.864), and

consumers (M=2.45, SD=0.981) were seen as less responsible roles. This distribution suggests a belief that those directly involved in the handling and preparation of food play a more crucial role in ensuring food security than food producers and consumers.

Though respondents had poor knowledge and attitudes toward food security, they have a moderate to high level of good food security practices daily, such as not frequent food purchases due to promotions or discounts (34.8% of them buy food because of promotions or discounts sometimes, and 29.9% rarely do it. M=2.9, SD=1.132) and frequent consideration of food security in daily operations (35.1% of respondents often consider food security in daily operations, and 14.9% always do it. M=3.68, SD=1.272).

It may remain a concern that respondents think the most prominent responsible role in the food value chain is direct food operation involvers, such as food processors and food service staff. The findings underscore the importance of targeted educational initiatives to bridge the knowledge gaps while reinforcing the positive behaviors already in place and policy focus on raising awareness about the importance of digital practices in agriculture for ensuring food security.

4.3.7 Cluster analysis of food security awareness

Similarly to the statistics analysis of the subchapter 4.3.5 regarding food safety awareness, cluster analysis was employed to identify and categorize the respondents regarding food security. The analysis revealed two notably distinct clusters, and only the main results were demonstrated in this subchapter.

Based on the respondents' varying behaviors related to food security awareness, knowledge, attitudes, and practices, they were effectively divided into two clusters as indicated by their z-scores across a range of variables, with 157 individuals in Cluster 1 and 171 in Cluster 2. Cluster 1, named "food security ignorant", displayed negative z-scores across all variables, reflecting a lower-than-average familiarity and agreement with food security concepts and performance in food security practices. Conversely, Cluster 2, named "food security aware" predominantly exhibited positive z-scores, which indicate a higher-than-average engagement with food security knowledge, attitudes, and practices. Participants in this cluster were more acquainted with and supportive of food security concepts and practices.

To verify the robustness of the results derived from the K-means cluster analysis, an ANOVA was conducted on the identified clusters to assess the validity and effectiveness

of the clustering outcomes. The Sig. (p-value) for nearly all variables is 0.000, signifying that the differences between the clusters are statistically significant at the 0.05 level (p<0.05). There is only one variable that has no significant difference in the two clusters, "Frequency of buying food because of promotion or discount" with a p-value of 0.454, but this result eliminated the potential controversial assumption that respondents in Cluster 1 may have less food waste. The ANOVA analysis indicates that the clusters represent groups with distinctly different levels of familiarity, agreement, attitudes, and practice toward food security.

Once the clusters were identified and validated, the socio-demographic characteristics of each group—including factors like age, gender, residential area, education level, current occupation, monthly income, religion, dietary habits, and their role in the food value chain—were analyzed and summarized. Cluster 1, "food security ignorant", is formed by younger rural citizens with significantly lower education levels and lower monthly income, and there is a significant number of them are students. In contrast, Cluster 2, "food security aware", are older city citizens with significantly higher education levels and higher income, and employed. To summarize, education, current occupation, and monthly income are significantly different characteristics among clusters.

4.3.8 Respondents' perception of the solutions to raise food safety and food security awareness across the food value chain

As subchapter 4.3.2 proved that food safety awareness and food security awareness are interrelated, this subchapter was given to explore the effective solutions to raise awareness. Based on a comprehensive review of the literature and an analysis of current societal trends, we identified six potential strategies aimed at increasing individual awareness of food safety and food security. These strategies encompass the role of education and training in translating knowledge into everyday practice, the impact of youth engagement as global citizens, the importance of early education targeting kindergarten-age children and youth, the critical role of government interventions, the influence of social media influencers on individual behavior, and the use of digital games specifically designed for the 12-18 age group. At the end of the survey, respondents were asked about their opinions on the different solutions to raise awareness of food safety and rated from the four-point Liker Scale (from 1 to 4, it represents "not at all," "slightly," "very," and "extremely").

The results were analyzed using a percentage (Figure 5), mean, and standard deviation (Figure 6). The role of government is significantly regarded as more important than any other strategy, with the highest frequency of positive agreement (297, 90.6%) and low frequency of disagreement (41, 9.4%). The highest mean value (3.43) and lowest standard deviation (0.687) mean the highest average agreement in its role and small level of different opinions among respondents. The next significantly important solution to raising individual food safety awareness is the role of the early start of education since kindergarten or youth (289 positive agreement, 39 negative agreement, M=3.3, SD=0.698). "The role of youth in contributing as global citizens" (273 positive and 55 negative) and "Education and training in transforming knowledge into daily practice" (254 positive and 74 negative) are also important solutions with a high frequency of agreement and low frequency of disagreement, and there a bit smaller mean value and bigger standard deviation (M=3.13, SD=0.698; M=3.05, SD=0.742). It means these two strategies are a bit less important, and respondents have different opinions. Considering the modern style and the role of the internet, respondents have hesitant opinions but are slightly positive. In comparison to digital games targeting the 12-18-year-old population (186 positive opinions, 142 negative opinions), they prefer the role of influencers to message individuals (229 positive opinions, 99 negative opinions). The relatively lower mean value, 2.93 and 2.64, respectively, and high standard deviation value, 0.847 and 0.96, respectively, mean that respondents have complicated opinions about these online strategies but are still positive.

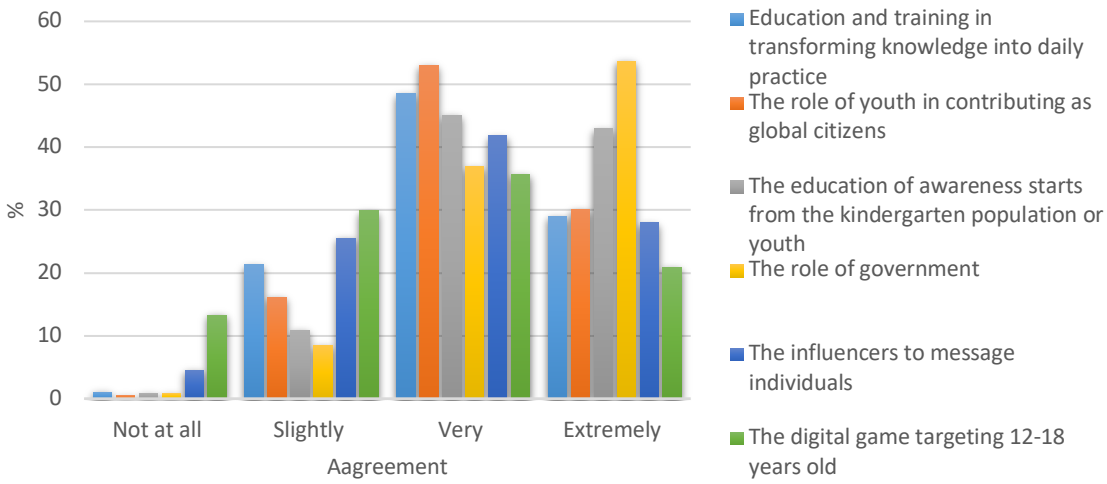

Figure 5 The percentage of respondents' agreement with different awareness-raising solutions, N=328
Source: authors' own construction

Figure 6 The Mean and Standard Deviation of respondents' agreement with different awareness-raising solutions, N=328

Source: authors' own construction

Overall, the chart highlights a preference for traditional strategies, such as government involvement and early education, while modern strategies, like digital games and influencer messaging, garnered more varied and less enthusiastic support.

4.4 Farmers' role in ensuring food security from the perspective of digital agricultural production (Result of CS 4. Farmer's perception of digital agricultural technologies)

Five agricultural practitioners accepted the interview and consented to the recording purpose and content of the research. Their diverse backgrounds represented the agricultural culture in Bayannur well. In the results section, a detailed investigation of each interviewee was given. Ten themes were presented according to different research questions in each subchapter. The relationship between research questions, themes, and codes was summarized as a Cmap (Figure 7) and demonstrated after.

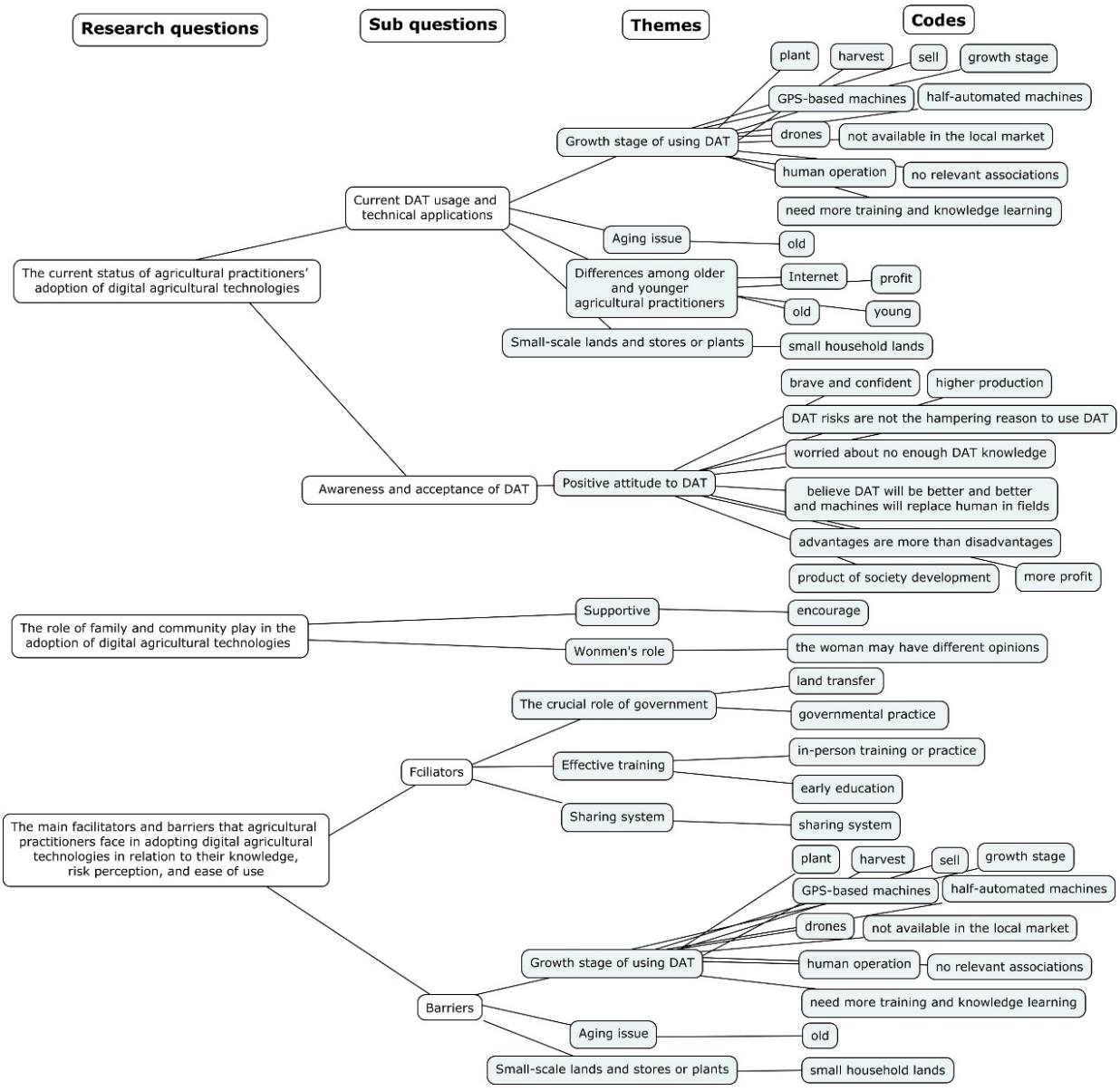

Figure 7 The relationship between research questions, themes, and codes
Source: authors' own research

4.4.1 The current status of agricultural practitioners' adoption of digital agricultural technologies

4.4.1.1 Current DAT usage and technical applications

Growth stage of using DAT:

The use of DAT is still in a growth stage, which can be seen from the limited application, availability, advance, reality restriction (small scale lands or stores), immature human operation, and risks perceived by agricultural practitioners. Since the Internet started to be commonly affordable around 2015 in Bayannur rural areas, agricultural practitioners have gradually used the Internet for their convenience in agricultural practice. In recent

years, short video platforms become popular among agricultural practitioners for accessing information related to climate, product prices, agricultural machine information and price, plant disease, and so on for cultivation, harvesting, and selling. However, they do not mention the use of data analysis or AI methods, for instance, "… for information to make sure good cultivation and good selling. Search information about product prices for next year's cultivation plan, machines, crop management, when to use pesticides, look for a job, policy influence to agriculture" (Mr. Wu), "Make and post short videos about seeds (yields, changes) for marketing and sell on short video platform" (Mr. Liu). Some practical technologies, such as crop disease monitoring systems, digital drip irrigation systems, fully automatic sprinkler systems, and automated fertigation, are not available in the local market, "Many digital technologies are not available in the local market as digitalization is still in beginning stage in Bayannur" (Mr. Cui). Some available DAT has practical issues, such as, "I use sunflower seed color sorter to categorize seeds based on insect damage, color, and plumpness, and then sell to roasted seed and nut factories or export to Middle Eastern countries. This technology can replace human labor, increase production and production efficiency, reduce labor workload and it is convenient. I also want to use a robotic arm to package and arrange sunflower seeds. But the program design lacks specificity and flexibility, not as efficient and cost-effective as human work, too big, not able to solve an emergency, requires more space to work." (Mr. Gao). Due to the small-scale lands and small-scale store, some machines can be only half-automated, for instance, "I want to use GPS automated seedling planter (tomato, chili), GPS automatic film covering machine and drone fertilizer sprayer, but my land is too small or it is not profitable to use these DAT" (Mr. Wu), "I want to use gene-editing technology for breeding and digital seed sorter. But our store is small so we cannot afford to buy the advanced machine" (Mr. Liu). In Mr. Gao's plant, they purchase sunflower seeds directly from local farmers and use the digital sunflower seed color sorter to categorize seeds based on insect damage, color, and plumpness, and then sell to roasted seed and nut factories or export to Middle Eastern countries. Interviewees did not state many risks or specific risks from DAT, which may result from the immaturity and popularity of the technologies and the more issues may from the immature human operation, "… there are many uncertain elements as it is new advanced technology…" (Mr. Gao), "The more risks come from human reason who was operating, instead of the machine itself" (Mr. Wu).

Aging issue: With the rapid development of urbanization, more and more people are moving to the city from the village. More and more graduates choose to work in urban areas instead of farming in rural areas due to poor education and healthcare and fewer cultural activities. The aging issue is becoming increasingly critical in Bayannur's rural areas. The couple interviewees, born in the 1970s, are almost the youngest generation farmers. The young interviewee, Mr. Cui, was born in the 1995s and may be the only young farmer: "In this city, I am the only young farmer. Most of my peers do not want to return to the village to work. The new farmers leasing big amounts of land under land transfer policy are all around 40 years old". Not only the small-scale land farmers have aging issues, but also the owners of traditional agricultural service stores, such as seed sale stores. They cannot adapt to the new demand under the land transfer policy background as they are too old to learn the DAT. As the young interviewees mentioned, even if they need to learn the new technologies update, it is more difficult or impossible for their parents, who are still involved in agricultural practices or from whom they got the plant or store ownership. Mr. Cui also expressed his concern that "Nowadays, it is hard to employ a labor force in the villages as they are too old, machines cannot replace some work, and some work should be done in the evenings." "My family and I are worried about the future of our store and similar small stores like ours in the local agricultural market. As the farmers are getting old, they prefer to lease their small-scale lands to others or companies under the land transfer policy, which prefers to order big amounts of seeds from bigger seed companies rather than our stores" (Mr. Liu).

Differences among older and younger agricultural practitioners: Besides the working experience in agriculture, there was an apparent difference between traditional and young agricultural practitioners, particularly in the new DAT knowledge and management mindset. All interviewees use the internet to watch relevant short videos to learn, while the young agricultural practitioners spend relatively more time on it. Besides, young agricultural practitioners can master different sources to learn on the internet, such as using browsers fluently to search for answers and read articles, while traditional agricultural practitioners mostly rely on short videos. Even though Mr. Cui started agricultural practice two years ago, he has a lot of insights and ideas compared to the couple interviewees. Young agricultural practitioners are more business-thinking in farming. For instance, "I am open to try new DAT as long as it is profitable" (Mr. Cui), "… I consider the practicality and cost…" (Mr. Gao). However, the traditional ones are

concerned more about their age and ability to learn, “We are getting old and do not have enough knowledge” (Mr. Wu). The young agricultural practitioners are more specific about the DAT risk perception from their viewpoint. For instance, “…lack of DAT knowledge makes him at risk of being scammed and hesitating to invest…” (Mr. Cui), “My knowledge may restrict the use of DAT” (Mr. Gao).

Small-scale lands and stores or plants: Small-scale household land is common and is a feature of China’s agricultural lands, which works in concert with small-scale stores and plants. Therefore, it is no wonder that as small-scale lands are being integrated into a considerable scale under the land transfer policy, some related stores are being very profoundly influenced. The small-scale lands and stores or plants have difficulty applying DAT due to the high cost and big-scale requirements of DAT. Even though many lands are integrated into big-scale lands under the land transfer policy, the scale of the integrated land is still small to some extent to use some fully automated machines. For instance, Mr. Wu was feeling pity to say that his lands are too small to apply some digital machines, but he was very passionate about farming and had the interest to know more about DAT. Mr. Cui also expressed his concern the scale of the land is too small, and he has to use half-automated machines, which is a social issue, “I know there are fully automated harvest machines, but I cannot use them in my fields because the scale of the land is too small to use” (Mr. Cui). “Our store is small, so we cannot afford to buy the advanced machine.” (Mr. Liu).

4.4.1.2 Awareness and acceptance of DAT

Positive attitude to DAT: The risks from technologies themselves are not a big issue or the reason hampering agricultural practitioners’ use, such as data stability, data security, data reliability, complexity, and cost. The weak DAT risk awareness can also accelerate the application of DAT. All the interviewees were very positive during the interview and had an excellent impression of DAT in their work. They evaluated the advantages and disadvantages of DAT, and they believe DAT will replace human force to some extent and DAT will be better and better as a product of society’s development. For instance, Mr. Wu was excited about this interview and highlighted many times that he would like to try the new digital technologies in practice, which makes him feel like “farming scientifically” instead of the current “farming by experience”. Mr. Cui expressed his motivation and confidence in utilizing digital agricultural technologies in his work since he witnessed the difference between being a rare young “farmer” who keeps learning

digital technologies and farming knowledge and the local "traditional" old farmers who do farming based on experience. "I am confident to use" (Mrs. Wu and Mr. Liu). "I am confident to use DAT and I believe DAT will be better and better" (Mr. Gao).

4.4.2 The role of family and community in the adoption of digital agricultural technologies

Supportive: Interviewees' families or their employees encourage using DAT, and some are trying to learn about DAT as well. Interviewees also encourage them to learn because their families and employees are old. For instance, "My family agreed and encouraged to use DAT, but more worried that more and more farmers will lose their jobs due to land transfer. However, we must admit that most farmers are above 50 years old, and those older than 60 have to transfer lands because of their age" (Mr. Wu). "My families or employees in the fields are relatively old. They barely know or try to understand DAT. Even though it is hard for them to accept, I should encourage them to know" (Mr. Cui). "We all accept and support its use because it saves labor and time" (Mrs. Wu). "My parents are more than 50 years old, but they support me to learn and use. They are also really interested and want to learn the advanced technologies but are too old for it" (Mr. Liu). Mr. Gao is very strict about his employees' attitude as they are the DAT operators, but he is satisfied, "My families all agree and support using DAT and trying to learn about it. My employees are also willing to learn".

Women's role: As the only female interviewee, Mrs. Wu has a basic understanding of DAT compared to other interviewees. However, there are some distinguished differences in her opinion about DAT and her agriculture practices. Instead of worrying about personal knowledge about DAT, Mrs. Wu worried that minor individuals or companies manage most lands under the land transfer policy, and these "businessmen" may only cultivate cash crops, which can result in a weak agricultural products market. Generally, minor individuals, such as interviewee Mr. Cui, lease many lands under the land transfer policy for a fixed few years and do not live in the village. As these businessmen are not long-term land managers, they may damage the soil fertility and environment for temporary profit or only choose the crop type to get the governmental subsidy. The concern about agricultural sustainability can only be seen from Mrs. Wu rather than any other male interviewees. However, her answers are relatively simple and do not share much DAT knowledge, practice, or awareness of DAT risks compared to male interviewees. For instance, "I barely look up the internet for agricultural practice" (Mrs.

Wu). When interviewees were asked about their risk perception of DAT from their viewpoint, they expressed a welcoming attitude but were concerned about their limited knowledge. However, she was not worried and believed the specific staff would do it instead of her, "I don't worry about my DAT knowledge because there are specific people to do it" (Mrs. Wu). "I do not worry that there is not enough service for me to increase my DAT knowledge because there are technical service personnel, and we farmers do not need to know too much about DAT" (Mrs. Wu).

4.4.3 The main facilitators and barriers that agricultural practitioners face in adopting digital agricultural technologies in relation to their knowledge, risk perception, and ease of use

4.4.3.1 The facilitators for agricultural practitioners to adopt DAT

The crucial role of government: The government plays a vital role in DAT development in Baynnur. One of the most important policies is the land transfer. A few individuals or companies who are relatively younger than the traditional farmers lease considerable amounts of land from small individual households and integrate them into the bigger scale of land. The integrated lands allow some advanced technologies to operate but sometimes are still not big enough. Mr. Cui repeatedly emphasized that his lease is still too small to adopt automated machinery, which he would like to use. And these new farmers who have enough financial resources can also afford more DAT than small household farmers. For instance, using drones to spray pesticides is very common for new and traditional farmers, while only the new farmers can afford to use drones to spray fertilizers. Due to the requirement of land scale, only new farmers are able to use half-automated seedling planters (tomato, chili) to cultivate. This policy may cause some challenges for small stores' operations, such as Mr. Liu's seed sales store. Under pressure, Mr. Liu and his family are considering changing their business to modern technology services, such as drone repair, "The government policy significantly impacts our store. Because of the land transfer policy, there are fewer and fewer small-scale farmers who buy seeds from my stores, and this makes us think about switching careers to drone service stores to adapt to the DAT era". Besides the land transfer policy, the export policy is also very important in Bayannur. For instance, Mr. Gao's sunflower seed purchasing and initial processing plant mainly exports products abroad, such as in Dubai, Turkey, Egypt, and Iran. They benefited from the BRI policy a lot, such as from bank, customs, and clients' trust,

“Governmental policy, especially the BRI related to export significantly support us on the respects of custom, bank and clients willingness to come to China.”

Besides the vital role of government policy, interviewees have big confidence and dependence on the government’s role in DAT promotion and DAT knowledge training. For example, “When government encourages us to cultivate food crops, we have confidence. The government organizes training about DAT annually, so we do not have to worry about the learning sources. I think it is helpful when the government conducts on-site promotions in rural areas for purchasing biodegradable mulch film and how to purchase it with our smartphones. I think the government should also organize the digital agricultural forum.” (Mr. Wu). “The government's promotion of DAT is very important, such as using drones to spray pesticides. I always pay attention to the information from the government and attend the agricultural-related events invited by the local government” (Mr. Cui). “I am surely worried about my limited DAT knowledge. Sometimes, our local government organizes in-person training. I hope the government organizes more training.” (Mr. Gao).

Effective training: In-person or on-site training is agreed by all interviewees as the effective training method compared to an online format. Another common opinion is that education about DAT, food security, and food waste should start as early as possible. Early education should start from kindergarten, but the teaching method and content should concern elementary school students. The collaboration between government and agricultural products suppliers or research centers can be a good measurement for farmers to understand and master the DAT efficiently. For instance, “The government is conducting on-site promotions in rural areas for purchase biodegradable mulch film and how to purchase by their smartphones... it is must to educate kids about DAT, but better for elementary school students because kindergarten kids are too young to understand” (Mr. Wu). “There are some agricultural research and innovation centers organized by universities and local government. Another effective method to increase my DAT knowledge can be visiting agricultural expos, visiting agricultural universities, learning from peers, including accepting interviews, paying attention to the information from the government, and attending online learning. But there is no relevant association for me to join… the earlier, the better, but the teaching method and content should be considered among different ages...” (Mr. Cui). “It is a must to educate kids about DAT from kindergarten. Good awareness should be cultivated at early ages” (Mrs. Wu). “…

definitely the in-person forums ... Online format is not too real… the earlier, the better, especially about not wasting food…" (Mr. Liu). "… government organizes in-person training. Machine factories organize road shows to present how to use and modify the machines and the new functions which make us learn fast. It is better than online study… the earlier, the better, but the teaching content should be considered, such as the concept and logic, not how to use the method or technology…" (Mr. Gao).

Sharing system: A sharing system of DAT seems to be more acceptable for its future among interviewees, as it is affordable for small-scale households rather than buying the entire machine, and it is profitable for new farmers who operate big amounts of integrated lands. "I will use DAT in the future when there is a good sharing system for machinery or a collaborative system because it is adaptable for small-scale lands" (Mr. Wu). "I will use DAT in the future when a good sharing system for machinery is available because our lands are too small. It will be too expensive to buy it" (Mrs. Wu). "I will use DAT as long as it can bring me profit" (Mr. Cui).

4.4.3.2 The barriers for agricultural practitioners to adopt DAT

The barriers for agricultural practitioners to adopt DAT come from the first part of subchapter 4.4.1 which discusses current DAT usage and technical applications, such as the growth stage of using DAT, aging issues, and small-scale lands and stores or plants.

4.4.4 Findings from secondary research

Digital/smart agriculture of agriculture 4.0 include but not limit to precison agriculture and Digital Agricultural Education is one of the elements hampering the implementation of ICT in agriculture [149]. DAE, as a young field is insufficient and lack of clear description and comprehensive teaching in school. The key for agricultural actors to adopt digital agriculture technlologies is to make them perceive these technologies, so in order to bridge IT and agriculture, DAE should start from all levels of education, even kindergardens. DAE and financial support in digital agriculture are inadequate in Hungary.

The main factors stopping Agriculture 4.0 are the weak awareness of farmers, lack of digital agriculture experts and institutions, unclear digital agriculture education and training, and the absence of policies and laws [150]. In the end, we also put forward some suggestions to tackle these challenges, such as improving infrastructure investment and

competency-building, taking care of the “future farmers”, strengthening data ownership and privacy, and enhancing the role of government in digital agriculture development.

5G provides higher speed and capacity, connecting the world, while GPS excels in positioning, navigation, and timing in agricultural production [151]. These technologies conserve natural resources, improve crop yields and food safety, and protect the environment. They also help producers mitigate natural disasters and climate change. Smart agriculture aims for maximum economic benefits, food production, minimal costs, and environmental impact.

The improper use of 5G and GPS may result in further catastrophic loss and potential risks. the security risks of 5G and GPS in agriculture, such as the passive and active attacks, 5G architecture core network risks, network access risks, hardware risks etc. from 5G technology, and the disruption of position and timing systems, confidential data loss etc. from GPS technology in agriculture. Besides, both 5G and GPS have the technology immaturity and high-cost constraints to be adopted in agriculture [152].

The future agriculture in China could benefit from the 5G the most than any other country and regions due to its advanced development in infrastrure and active leading in 5 standardization [153], [154]. ChinaBesides the leading development of 5G infrastructure, China is also guiding the early standardization of 5G protocols. Chinese representatives play a significant role in international standard-setting organizations, both qualitatively and quantitatively.

The revolution of the fourth industry accelerates the application of ICT in agriculture and the development of smart agriculture. The applications of ICT bring together information security risks and further challenge food loss and waste and food security [155]. There are notable threats and risks to the application of 5G and GPS, such as passive and active 5G information security attacks (Eavesdropping and traffic analysis, Jamming, DoS and DDoS, 5G architecture core networks, Network access, Primary infrastructure of information technology (IT) and information and communication technology (ICT), Data privacy and security, Authorized communication security, Malware Fake Data Security). The best solution to improve wireless network security is to raise awareness of threats,vulnerabilities, and security settings among the players, such as the network users and providers, which can also be applied to agricultural ICT information security.

The farmer, technology, and external factors formed the “Three Parties” relationship and explained that education, perception of risks and age of farmer, cyber security, data security and access to of technology itself (stability, reliability, accuracy, and access) and the external factors or the third party (policy, market, and others) are the main causes for the slow adoption of digital technologies in agricultural production [156].

Quantum machine learning (Quantum Machine Learning, QML) is a combination of quantum computers and traditional machine learning. This combination can handle complex, large data sets faster and more efficiently than traditional methods. Quantum computing's ability to process large, high-dimensional datasets more efficiently presents significant opportunities for agriculture, particularly in enhancing the precision and scalability of pest and disease detection systems.

we innovatively simplify this concept according to the relationship between producers or farmers and technology into “Three Parties” hindering the adoption of agricultural production technologies: farmers, technology itself, and the third party or external (policy, market, and others) (Figure 8). The farmer, technology, and external factors formed the “Three Parties” relationship and explained that education, perception of risks and age of farmer, cyber security, data security and access to of technology itself and the external factors or the third party (policy, market, and others) are the main causes for the slow adoption of digital technologies in agricultural production. We also highlighted that the flaws from the consistently developing technologies are in a very crucial place as the cause. We summarized the most important risks from the technology itself as stability, reliability, accuracy, and access. In the end, we suggest that future research continue with the results we obtained to explore the solutions to mitigate these hindering risks.

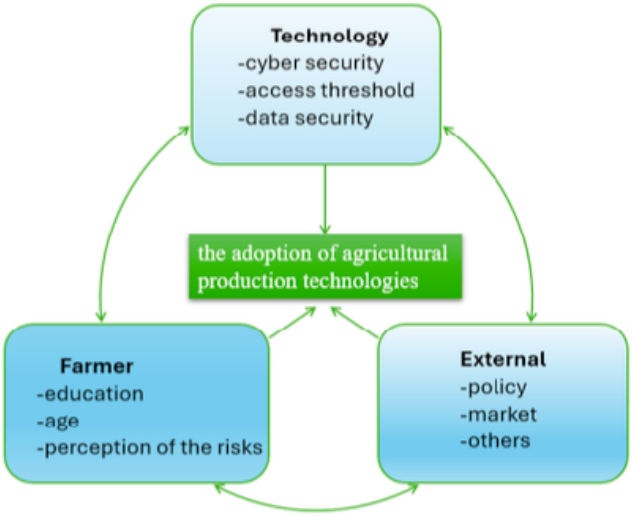

Figure 8 "Three Parties" hindering the adoption of agricultural production technologies

Source: own construction

4.5 Individual responsibility in ensuring food security from the perspective of food waste reduction (Results of CS 5. food waste behavior)

The questionnaire or scale has a very high internal consistency (α =0.899), suggesting that the items reliably measure the same underlying construct for four different parts questions on food waste.

4.5.1 Demographic

The 276 respondents are from 19 provinces or autonomous regions and abroad (mostly in Hungary). 266 (96%) respondents are from domestic, and 193 (70%) are from Inner Mongolia. Most of the respondents are around 26-40 years old. Female and male respondents are approximately even. Only 14.5% of respondents are from rural areas, which indicated that this research should not focus on living area factors associated with food waste behavior. Respondents exhibit a broad spectrum of educational backgrounds, and the employment and student status were distributed evenly, which made the survey more convincing. The average monthly income is 4000-6000 yuan, which is in the range of average monthly income from third-tier and smaller cities (5000 yuan), and this also meets the fact that the respondents are from this area.

Other basic information was also asked. Respondents were asked to choose whether they buy meals in the university canteen or company canteen (155, 56%) or cook at home or dormitory (121, 44%) during normal working days or school days and complete the

following questionnaire in this way. This approximately even percentage can be a good sample to distinguish between the two different eating styles and give specific suggestions for food waste reduction accordingly. Whether the food waste behavior is associated with religion (yes or no), student status (active or not), and food discipline study experience (studying or studied in food science and engineering faculty or not) is also interesting to investigate. However, the respondents who have religion are only 10, have an active student status of 81, and have (or had) food discipline study experience of only 24 (8.7%). Therefore, only some basic descriptive analysis of these factors can be conducted instead of deep analysis related to religion. Less than 7% of respondents are vegetarian or vegan, so the research can mainly focus on those who are non-vegetarian.

4.5.2 Descriptive analysis for food waste behavior

4.5.2.1 Food consumption habits

As assumed, the more often people purchase food or snacks in the market besides eating in the canteen or cooking by themselves, the more food waste because over-purchasing food may bring more leftovers. Therefore, respondents' food or snack purchase habits were asked about, and most of them (111, 40.2%) do the purchasing sometimes, 98 (35.5%) often, 55 (19.9%) rare. And "never" (4, 1.4%) and "always" (8, 2.9%) are two extreme purchase frequency. The frequency of food item types consumption was also asked (Figure 9). Many respondents consume rice often (59.1%) and always (19.6%). Noodles are another major staple food, with 48.9% often consumed and 10.1% always consumed. Bread is not a significant staple food among the respondents, and 18.1% and 1.4% of respondents rarely and never consume it. Regarding protein-rich food consumption, meat (55.4% often and 22.8% always) and dairy and egg (56.9% often and 18.8% always) are the main intake. Fish is the least intaken item with 4.3% never and 23.9% rarely consumption frequency. Fruits and vegetable intake are very frequent, and more consumers consume fruits (25.4%) and vegetables (29%) aways than rice consumption. Not many respondents consume all these food item types never (less than 7%) or rarely (less than 24%).

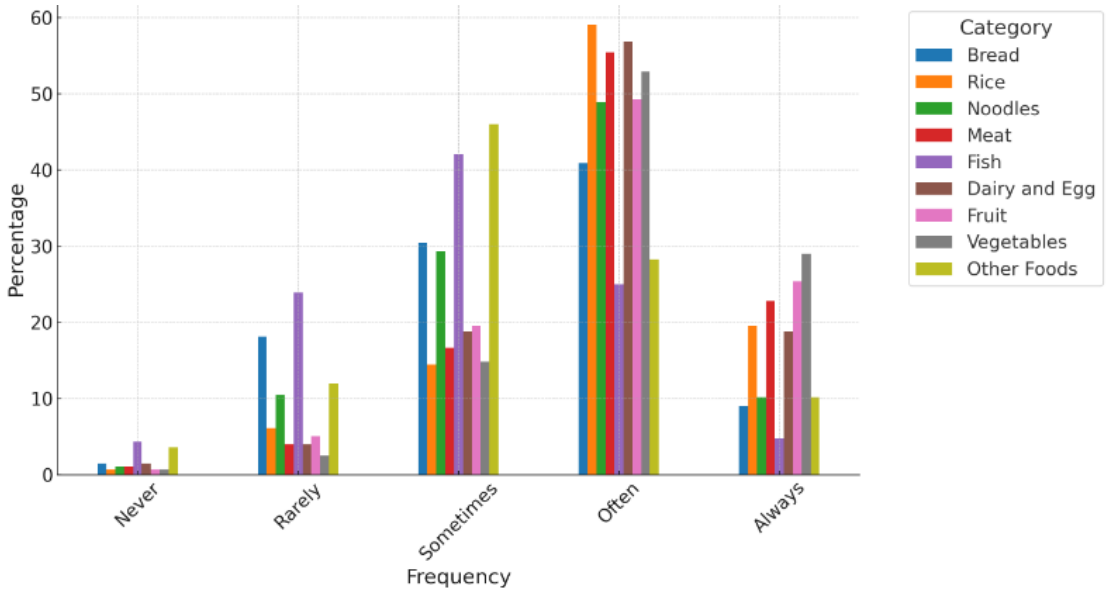

Figure 9 Frequency of food item types of consumption, N=276
Source: authors' own construction

The chart results show that respondents consume the given food item types regularly, indicating diverse and healthy diet habits. Rice is a significant staple food, with fruits, vegetables, and meat as the central diet, while fish is not popular. This result reflects the respondents have healthy diet habits.

4.5.2.2 Food waste attitude, knowledge, and awareness

It is believed that the respondents' attitudes, knowledge, and awareness play an important role in food waste behavior. More than half of them are positive about meal satisfaction, 47.8% are somewhat satisfied, and 18.1 are extremely satisfied. While they have relatively less positive reactions about confidence to finish plates, with only 18.1% very confident and 4.3% extremely confident, the negative attitudes are more with 31.2% slightly confident and 9.1% not confident at all, and moderate attitudes 37.3%.

Respondents' knowledge of food waste is evaluated by their perception of food waste defined by the UN, EU, US, and China (Figure 10) and the benefits of reducing food waste (Figure 11). It is distinguished that respondents agreed with the food waste definition defined by China the most, with the highest agreement (39.5% agree and 13% extremely agree) and lowest disagreement (5.4% extremely disagree and 4.3% disagree) ratio. And the respondents obviously disagree with the food waste definition defined by the UN, with the highest disagreement (8% extremely disagree and 23.2% disagree) and low agreement (26.8% agree and 6.5 extremely agree) ratio. Apparently, respondents agree with the food waste definition from the US (35.1% agree and 9.8% extremely agree)

more than the EU (33.3% agree and 4.3% extremely agree). The benefits of reducing food waste were classified into three different categories (society, environment, and economics), and respondents were asked to evaluate their perception of these benefits. Respondents appreciate the environmental benefits of reducing food waste the most, with the highest agreement on its importance and the lowest disagreement percentage, and the following important economic aspect. The social perspective regarding the benefit of reducing food waste ranked the lowest compared to environmental and economic aspects, with the highest disagreement about its importance (improve university's reputation: 10.1% and protect food security: 3.2%). Conserving precious energy and resources seemed to be the most important benefit of reducing food waste (0.7% not important, 0.7% less important, 31.2% somehow important, 54% very important). Protecting food security is ranked as the second most important benefit of reducing food waste from a social perspective, with 79.3% agreement of its importance. The following important factors are reducing the canteen's negative impact on the environment (79% somehow important or very important, and 4.3% not or less important), saving money from the thrown away food (74.3% somehow important or very important, and 3.3% not or less important), and increasing canteen's profit by investing in reducing food waste (66.6% somehow important or very important, and 6.2% not or less important).

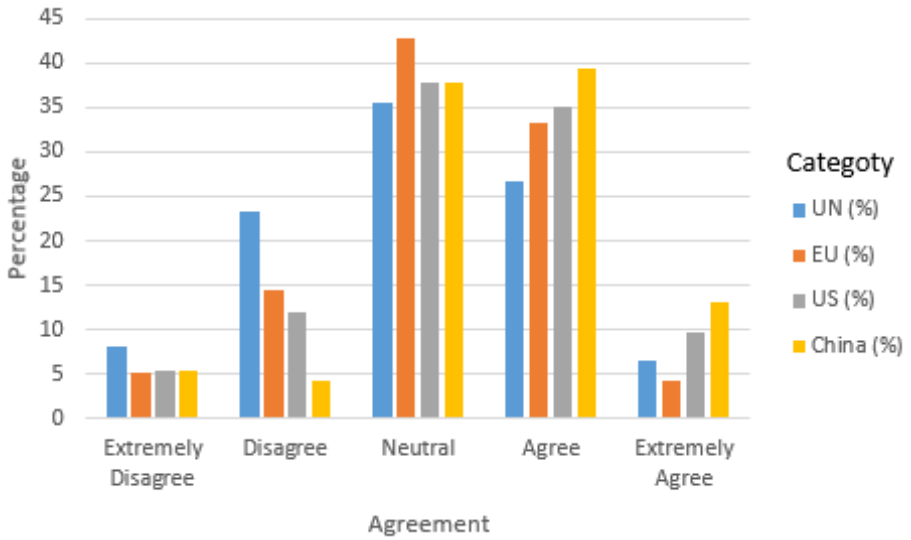

Figure 10 Respondents' perception of food waste defined by the UN, EU, US, and China, N=276
Source: authors' own construction

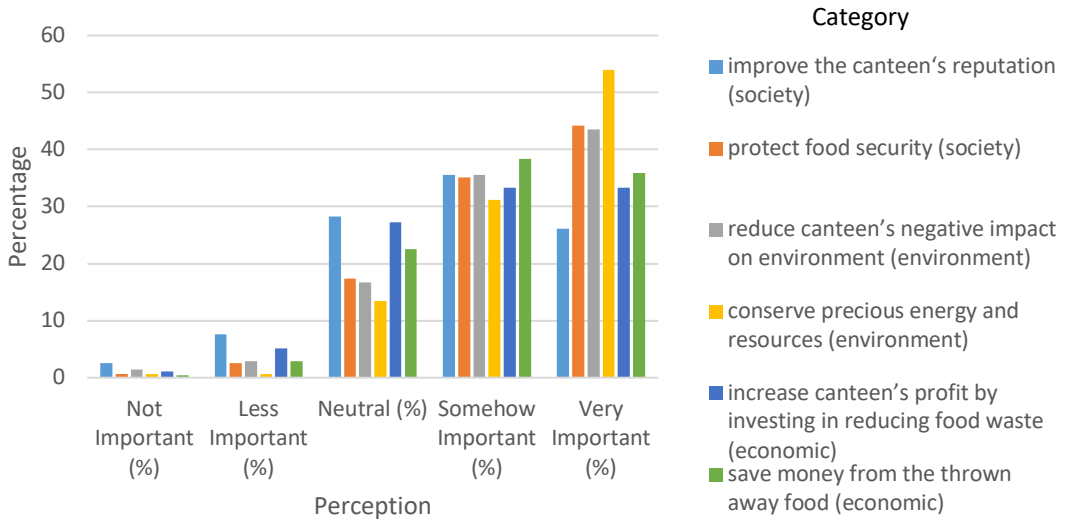

Figure 11 Respondents' perception of the benefits of reducing food waste, N=276

Source: authors' own construction

Respondents' awareness of food waste was demonstrated by their perception of food waste issues as food security or ethical issues and food waste problem level. For most respondents, the food waste issue is more likely to be an ethical issue, with 34.4% of them thinking it is somehow important, 43.1% saying it is very important, 2.9% saying it is not important, and 1.4% less important. 30.1% of them think food waste issues as food security issues are somehow important, 40.6% are very important, 5.4% are not important, and 4% are less important. Most of the respondents are aware of the serious level of food waste in their canteen or home and dormitory (50.4% of them think it is somehow serious and 10.9% think it is very serious).

4.5.2.3 Food waste behavior

About 30 (approximately 11%) respondents "never" waste food in daily life, which means 89% of respondents have wasted food daily. This large percentage means that food waste is quite a common phenomenon among the investigated Chinese people. Among the 246 respondents who have food waste experience, 151 (approximately 55%) of them seldom waste food, 79 (approximately 29%) of them waste food occasionally, and 14 (approximately 5%) of them waste food often. The extreme situation in which people always waste food is only 2 out of 276 (less than 1%). More number of respondents have food waste during dinner (59.8%) than at lunch (40.2%). Respondents waste food more on weekends (60.9%) than on weekdays (39.1%). In comparison to cooked food (82.2%), respondents waste much less fresh food (17.8%), such as salads. The most wasted food is "other food" given in the survey (23.9%), and the most frequent answer is "leftover food"

and “snacks”. In the following, the most wasted food is staple food, rice (22.8%) and vegetables (19.9%). The less wasted food is meat and fish (9.8%), bread, cereal and baked goods (9.1%), noodles (8.7%), and fruit (3.3%). The least wasted food item is dairy and egg (2.5%). When respondents were asked how much food they usually waste, 23.2% of them had none or hardly any, 15.2% of them wasted some, 6.5% of them had a bit big amount, and 0.7% of them had quite a lot. The majority of them (54.3%) usually have a small amount of food waste. Food waste amount was demonstrated in the survey as “ratio” (the amount of edible leftover divided by the amount of edible ordered food). Most of them have a small amount of food waste (45.7% waste none or tiny, 47.1% waste some, 5.1% waste half, 1.1% waste more than half, and 1.1% waste the most or all).

It can be inferred that while food waste is a widespread issue among the respondents, most individuals tend to waste food infrequently, with only a few consistently engaging in food waste and not a significant amount. The most wasted food is cooked food during weekend dinners, mostly rice and vegetables.

4.5.3 The determinants of food waste

4.5.3.1 Correlation analysis between potential causes and food waste behavior

In order to explore what affects food waste behavior (frequency and amount), demographic characteristics and food consumption habits were tested by Chi-square analysis, and Spearman’s analysis tested food waste knowledge and awareness.

Correlation analysis between food waste behavior and demographic characteristics

The result (Table 13) shows that gender (p=0.048) and highest education (p=0.000) are less than 0.05, which indicates a significant difference in food waste frequency. “Meals buyer or meals cook” with a p-value of 0.062 in food waste frequency, which is close to 0.05, which means this factor is a near-significant association. Meal preparation habits may influence food waste frequency, but not significantly at the conventional alpha level. The student status and their current or former faculty with the same p-value of 0.031 indicated that student status and their faculty have a significant association with food waste amount.

Table 13 Chi-square test for the association of demographic characteristics affecting food waste behavior, N=276

	Variables	Pearson Chi-Square	Degrees of Freedom (df)	P-Value
Frequency of food waste daily	Age	19.276	24	0.737
	Gender	15.168	8	0.048
	Living area	2.765	4	0.598
	Highest degree	69.667	24	0.000
	Current occupation	29.656	20	0.076
	Monthly income	8.708	12	0.728
	Religion	3.058	8	0.931
	Student status	5.997	4	0.199
	Faculty	3.348	4	0.501
	Meals buyer or meals cook	8.959	4	0.062
Amount of of food waste	Age	30.173	24	0.180
	Gender	14.169	8	0.077
	Living area	2.590	4	0.629
	Highest degree	35.457	24	0.062
	Current occupation	30.424	20	0.063
	Monthly income	9.895	12	0.625
	Religion	2.941	8	0.938
	Student status	10.602	4	0.031
	Faculty	10.636	4	0.031
	Meals buyer or meals cook	4.965	4	0.291

Source: author's own construction

These findings suggest that demographic factors significantly correlate with food waste behavior. For instance, education level and gender may influence food waste frequency, and student status and faculty may influence food waste amount. Meal preparation habits may influence food waste frequency, but not significantly at the conventional alpha level. This insight could inform targeted interventions and guide further research into the factors affecting food waste.

Correlation analysis between food waste behavior and food consumption habits

The association between food consumption habits and food waste frequency was tested by Spearman's analysis. However, the Chi-square test was conducted to assess the association of food habits (non-vegetarian, vegetarian, and vegan) with food waste frequency and amount instead of Spearman's test. The Chi-Square test statistic was 17.867 with 8 degrees of freedom, and the p-value was 0.022 for food habits and food waste frequency. For food waste amount, the Chi-Square test statistic was 6.419 with 8 degrees of freedom, and the p-value was 0.600. Since the p-value is less than the significance level of 0.05, it is concluded that there is a significant association between food habits and the frequency of food waste, but there is no significant association between food habits and food waste amount.

The Spearman's rank correlation coefficients revealed significant correlations among various food type consumption frequencies and frequency of purchasing food or snacks besides eating in the canteen or at home/dormitory. For instance, the consumption of bread is significantly correlated with the consumption of rice ($\rho = 0.345$, $p<0.01$), noodles ($\rho = 0.269$, $p<0.01$), meat ($\rho = 0.273$, $p<0.01$), and other food types. These correlations suggest that individuals who frequently consume one type of food are likely to frequently consume other types as well. However, the analysis did not reveal significant correlations between the frequency or amount of food waste and the consumption frequency of specific food types. This indicates that food consumption patterns are interrelated, they do not significantly impact the frequency or amount of food waste. There is a significant correlation between the frequency of purchasing food or snacks besides eating in the canteen or at home/dormitory and food waste frequency and amount.

As evidenced by the correlation coefficients, respondents' food habits are significantly related to how often they waste food but not how much they waste. The frequency and amount of food waste are significantly associated. The frequency of purchasing food or snacks besides eating in the canteen or at home/dormitory is not only significantly related to food waste frequency, but also food waste amount. While food consumption patterns, such as bread, rice, noodles, etc., do not have a significant association with food waste frequency and amount.

Correlation analysis between food waste behavior and food waste attitude, knowledge, and awareness

The association of respondents' attitudes, knowledge, and awareness and food waste behavior was examined by Spearman's rank correlations. The respondents' attitude was manifested by confidence to finish and satisfaction with the meals, as the result explained (Table 14). Respondents' knowledge and awareness were measured by their understanding of food waste and the benefits of food waste reduction, as the result proved. According to the bivariate Spearman rank correlations, there is a significant association between food waste behaviors. For instance, food waste frequency has a significant correlation with the food waste amount ($\rho=0.551$, $p<0.01$). A similar result can be found in food attitudes. For instance, respondents' confidence to finish meals has a significant correlation with their satisfaction ($\rho=0.302$, $p<0.01$). There is also a significant correlation between respondents' confidence to finish meals and food waste amount.

Table 14 Spearman's rank correlations between food waste behavior and food consumption attitude, N=276

		1.	2.	3.	4.
1. how often do you waste food daily	Correlation Coefficient	1.000			
	Sig. (2-tailed)	.			
2. how much food do you waste usually	Correlation Coefficient	0.551**	1.000		
	Sig.(2-tailed)	0.000	.		
3. how confident were you that you will finish your food when you want to order the specific food in most cases	Correlation Coefficient	-0.066	-0.158**	1.000	
	Sig.(2-tailed)	0.274	0.009	.	
4. how satisfied were you with your meal in most cases	Correlation Coefficient	-0.064	-0.066	0.302**	1.000
	Sig.(2-tailed)	0.292	0.275	0.000	.

Source: author's own construction, *p<0.05, **p<0.01.

Due to the page limit, the result was given instead of the statistics table. It can be concluded that respondents' awareness of food waste (what do you think the food waste problem in your university canteen or at home/dormitory) has a significant association with food waste frequency (ρ=0.252, p<0.01). Respondents' knowledge of food waste (ethic issue) is significantly associated with food waste frequency (ρ=-0.147*, p<0.05). The food waste knowledge of respondents (definition and food waste is classified as whether food security or ethical issue) have a significant association with awareness (food waste level in their daily life, benefits of food waste reduction). For instance, there is a significant association between respondents' knowledge of food waste definition in EU and UN (ρ=0.474**, p<0.01). This significance can also be found between respondents' awareness of food waste as an ethical issue and food security (ρ = 0.496**, p <0.01), the benefit of food waste reduction as improving reputation and protecting food security (ρ=0.621**, p<0.01).

In the results of bivariate Spearman rank correlations for respondents' attitudes, knowledge, awareness, and food waste behavior, it was concluded that respondents' attitudes may affect food waste amount. Respondents' knowledge of food and awareness may significantly impact food waste behavior.

4.5.3.2 Regression analysis between potential causes and food waste behavior

In this section, the potential causes were examined by regression analysis, and the food waste amount was estimated by the food waste ratio due to data availability.

Regression analysis between food waste frequency and potential causes

The ordinal logistic regression analysis was utilized to explore the relationship between all predictors and the frequency of food waste (Table 15), instead of only the obtained

significant factors from Chi-square and Spearman's rank correlation analysis. The analysis utilized the 'Logit' link function and incorporated various demographic predictors into the model. The model with predictors fits significantly better than the intercept-only model (χ^2=616.132, p=0.000). The model fits the data well (Pearson χ^2=152.121, p = 1.000 and Deviance χ^2=132.175, p = 1.000). Pseudo R-Square (Cox and Snell=0.893, Nagelkerke=1.000, and McFadden values=1.000) indicates this model explains a reasonable amount of the variance. The test of parallel lines was not significant (χ^2 = 0.000, p = 1.000), indicating that the proportional odds assumption held. In contrast, the model including only the significant predictors failed the test of parallel lines (χ^2 = 473.190, p = 0.000). These results suggest that the full model provides a more robust and accurate representation of the data by accounting for potential confounding factors and capturing the complex interactions among the predictors.

Table 15 Ordinal logistic regression analysis for each predictor variable and their significance, N=276

		Estimate	Std. Error	Wald	df	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Thres-hold	[how often do you waste food daily = 1]	11.598	18.760	0.382	1	0.536	-25.171	48.366
	[how often do you waste food daily = 2]	22.847	18.917	1.459	1	0.227	-14.230	59.924
	[how often do you waste food daily = 3]	28.720	19.071	2.268	1	0.132	-8.659	66.098
	[how often do you waste food daily = 4]	32.639	19.085	2.925	1	0.087	-4.766	70.045
Locati-on	[age=1]	-9.229	3.514	6.899	1	0.009	-16.116	-2.342
	[do you have religion=1]	-5.650	2.513	5.055	1	0.025	-10.575	-0.724
	[how often do you consume the food types, bread=4]	4.712	1.693	7.749	1	0.005	1.394	8.030
	[meat=3]	-3.919	1.318	8.845	1	0.003	-6.502	-1.336
	[meat=4]	-2.188	1.084	4.074	1	0.044	-4.312	-0.063
	[how do you evaluate the definition of food waste, UN=1]	5.035	2.552	3.892	1	0.049	0.033	10.038
	[EU=4]	4.858	2.436	3.976	1	0.046	0.083	9.633
	[China=1]	-7.003	2.445	8.202	1	0.004	-11.795	-2.210
	[what do you think the food waste problem in canteen or home=1]	-8.741	3.973	4.839	1	0.028	-16.528	-0.953
	[what do you think the food waste problem in canteen or home =2]	-4.819	1.776	7.361	1	0.007	-8.300	-1.338
	[what do you think the food waste problem in canteen or home =4]	-2.784	1.401	3.950	1	0.047	-5.529	-0.038
	[what do you think about the benefits of reducing food waste in canteen=1]	5.869	2.947	3.966	1	0.046	0.093	11.646
	[increase canteen's profit by investing in reducing food waste=1]	-18.677	8.799	4.506	1	0.034	-35.923	-1.431
	[what food type do you waste the most=1]	4.882	1.599	9.325	1	0.002	1.748	8.015
	[what food type do you waste the most =2]	2.810	1.156	5.913	1	0.015	0.545	5.075
	[what food type do you waste the most =4]	5.000	1.519	10.841	1	0.001	2.024	7.976
	[how confident were you to finish=2]	5.889	2.558	5.300	1	0.021	0.875	10.903
	[how confident were you to finish =3]	4.959	2.491	3.962	1	0.047	0.076	9.842
	[how confident were you to finish =4]	8.321	2.638	9.950	1	0.002	3.151	13.492
	[how satisfied were you with meal=1]	7.185	2.345	9.391	1	0.002	2.590	11.780

Source: author's own construction

Due to the limit of the pages and the exclusive predictors, the results were only given by those factors that have a significant relationship with food waste frequency. The original logistic regression analysis showed that food waste frequency has positive relationship with the frequency of food type consumption (bread 4: β= 4.712, p= 0.005), perception of food waste definition (UN 1: β= 5.035, p= 0.049); EU 4: β= 4.858, p= 0.046), perception of food waste reduction benefits (improve reputation (society) 1: β= 5.869, p= 0.046), the food type being wasted the most (bread, cereal and baked goods: β= 4.882, p= 0.002; rice: β= 2.810, p= 0.015; meat and fish: β= 5.000, p= 0.001), confidence of finishing plate 2: β= 5.889, p= 0.021, 3: β= 4.959, p= 0.047, 4: β= 8.321, p= 0.002), satisfaction with the meal (β= 7.185, p= 0.002).

And food waste frequency has negative relationship with age (1: β=-9.229, p=0.009), religion (yes β= -5.650, p=0.025), frequency of food type consumption (meat 3: β= -3.919, p=0.003; 4: β= -2.188, p= 0.044), perception of food waste definition (China 1:β= -7.003, p= 0.004), perception of food waste level (1: β= -8.741, p= 0.028; 2: β= -4.819, p= 0.007; 4: β= -2.784, p= 0.047), perception of food waste reduction benefits (increase profit (economics) 1: β= -18.677, p= 0.034). Besides, respondents' food waste frequency has a positive relationship with the perception of food waste definition from the UN and EU but has a negative relationship with the Chinese (1) definition (β= -7.003, p= 0.004) and no relationship with the definition from the US. The positive relationship indicated that as the predictor increases, the dependent variable will also increase, and vice versa. For instance, when respondents consume more bread, the frequency of their food waste behavior could also increase. As age increases, the frequency of food waste frequency could decrease.

Regression analysis between food waste amount and potential causes

A similar statistics analysis method was used to examine the relationship between the food waste ratio (the amount of edible leftovers divided by the amount of edible ordered food) and the possible predictor. As the result proved, there is a significant positive relationship between food waste ratio and age (2: β= 11.946, p= 0.008; 3: β= 14.394, p= 0.003; 4: β= 15.006, p= 0.003); 5: β= 11.508, p= 0.009; 6: β= 11.184, p= 0.007), living area (rural: β= 4.371, p= 0.003), highest education (4: β= 6.541, p=0.028; 6: β= 4.377, p= 0.017; 7: β= 5.087, p= 0.015), monthly income (1: β= 5.236, p= 0.004), frequency of food types consumption (meat: β= 3.119, p= 0.037; dairy and egg 2: β= 8.562, p= 0.015; dairy and egg 3: β= 9.076, p=0; vegetable 3: β= 7.974, p= 0), the frequency of food or snacks purchase in market besides eating in canteen or at home/dormitory (β= 7.382, p= 0.016), perception of food waste definition (China 3: β= 4.524, p= 0.009), perception of food waste issue (food security 1 β= 5.455, p= 0.028; food security 3 β= 5.736, p= 0.002; food security 4 β= 6.816, p= 0); ethic issue 2: β= 10.574, p= 0.013), perception of food waste reduction benefits (reduce university canteen's negative impact on environment (environment) 4: β= 3.456, p= 0.022; save money from the thrown away food (economic) 4: β= 5.215, p= 0.022), food type of the most food waste (rice: β= 4.21, p= 0.005; noodles: β= 4.135, p= 0.023; meat and fish: β= 11.094, p= 0; vegetables: β= 4.664, p= 0.004), satisfaction with the meal (β= 6.001, p= 0.036).

And those factors have negative relationship with food waste ratio are religion (yes: β= -9.171, p= 0.008), meal preparation (meals buyer: β= -3.744, p= 0.002), frequency of food types consumption (rice 3: β= -4.295, p= 0.02; noodles 3: β= -7.182, p= 0.002; noodles 4: β= -4.253, p= 0.042; fish: 2: β= -9.936, p=0.009; 3: β= -6.747, p= 0.041; 4: β= -10.105, p= 0.007; fruit 3: β= -7.326, p= 0.002; vegetable 2: β= -11.02, p= 0.011; other 1: β= -13.647, p= 0.001; other 2: β= -3.761, p= 0.039), perception of food waste definition (China 1: β= -6.341, p= 0.043), perception of food waste issue (ethic issue 4: β= -5.066, p= 0), perception of food waste level (2: β= -4.183, p= 0.022; 3: β= -10.26, p= 0; 4: β= -6.325, p= 0.001), perception of food waste reduction benefits (reduce university canteen's negative impact on environment (environment) 2 β= -11.627, p= 0.009; conserve precious energy and resources (environment) 4: β= -3.653, p= 0.016), the meal with more food waste in one day (lunch 1: β= -2.981, p= 0.006), period with more food waste (weekdays: β= -1.851, p= 0.039), condition of the most food waste (fresh food: β= -3.068, p= 0.014), food type of the most food waste (fruit: -8.125, p= 0.006), the most common reason to throw away food in can teen (no idea: β= -12.389, p= 0.001; not tasty: β= -15.347, p= 0; order/cook too much than estimated: β= -14.113, p= 0; no enough time to finish: β= -10.391, p= 0.008; the unit served portion size is too big: β= -13.775, p= 0; food quality is bad: β= -17.107, p= 0), satisfaction with the meal (β= -5.226, p= 0.009).

As the coefficient value and p-value indicate the relationship between food waste frequency and possible predictors, age has a significantly negative association with food waste frequency, which revealed that food waste frequency may decrease among older respondents. Having a religion may help people to reduce food waste frequency. More bread consumption may result in more food waste frequency compared to other types of food items, while more meat consumption may have less food waste frequency. When respondents perceive the food waste definition by the UN and EU better, they may waste food more often, but the frequency of food waste could be less frequent when they perceive the Chinese definition better. Awareness of respondents in food waste problems may have an important influence because those who perceive the food waste problem in their daily lives as more serious may have less frequent food waste. Those who are aware of the benefits of food waste reduction in social aspects, such as "improve reputation" instead of "protect food security", may have more often food waste than those who are aware of the benefits of food waste reduction in economic and environmental aspects. When respondents realize the economic benefit of food waste reduction, such as "increase

profit" instead of "save money", they waste food less frequently. The respondents' attitudes also have a significant association with food waste frequency. When they are more confident of finishing their meal and more satisfied with their meals, they may waste food more often.

To provide a comprehensive investigation and deep understanding of food waste behavior, the food waste amount question was also analyzed, which was demonstrated as a ratio of food waste in the survey. The coefficient value and p-value revealed that older respondents may have a higher ratio of food waste than younger respondents. Respondents living in rural areas may have a higher ratio of food waste than those living in the city. When respondents have a higher monthly income, they may tend to waste more food. Those who have religion may have less food waste than those who do not. The survey indicated two different types of meal preparation: meals bought in the university/company canteen and meals cooked at home/dormitory. Meals buyers tend to waste less food than the other. Many food types of consumption have a significant relationship with food waste amount. For instance, the more often meat, dairy and egg, and vegetables are consumed, the higher the ratio of food waste. while those respondents who like to consume rice, noodles, fish, and others more often may have less food waste. Respondents' food consumption habits besides normal meals may also bring more food waste, such as the more frequent food or snacks purchased in the market besides eating in the university/company canteen or at home/dormitory. When respondents better perceive the definition of food waste in China, they may waste more food. Respondents who have a better perception of food waste as a food security issue may also result in more food waste, but when they perceive food waste issue as an ethical issue, they waste less food. When the food waste problem level is perceived better, the food waste might be less. The more food waste could also be from respondents' better perceptions of food waste reduction benefits as environmental (reducing the canteen's negative impact on the environment) and economic (saving money from throwing away food). But food waste might be decreased when respondents perceive the benefits of food waste reduction on the environment (conserving precious energy and resources), other than economic and social aspects. Compared to dinner, lunch may be the meal most respondents waste less food on. Weekdays may be the time period most residents waste less food compared to weekends. In comparison to cooked meals, fresh food is wasted less by most respondents. The respondents who waste more food usually waste rice, noodles, meat and fish, and

vegetables the most. When respondents have no idea why they throw away food, the food is not tasty, they order/cook too much than estimated, they do not have enough time to finish, the unit served portion size is too big, or the food quality is bad, they tend to waste less food. Respondents who are more satisfied with their meals may waste more.

4.5.4 Predictions for effective food waste reduction strategies

The reasons for wasting food were examined directly from respondents' self-evaluation reports. The main reasons are "ordered or cooked too much than estimation" (23.6%), "not tasty" (23.2%), and "the unit served portion size is too big" (21.7%). The highly-voted reason for "not tasty" was also chosen by respondents when they were asked about the most often wasted food item type. "Bad food quality" is considered another important reason for food waste, with 17.8%. The rest given reasons seem not significant for respondents' food waste behavior, such as "emotion was not good or with a high level of stress" (1.4%), "not enough time to finish" (5.4%), and "do not know" (6.9%). In accordance with respondents' dining habits, the strategies given to examine are divided into canteen and home or dormitory.

The descriptive statistical results of evaluating the effectiveness of various strategies to reduce food waste using a 5-point Likert scale were summarized by percentage from four different directions: behavioral-change intervention in the canteen (Figure 12), infrastructural interventions in the canteen (Figure 13), infrastructure interventions at home (Figure 14), and university/company canteen or home/dormitory (Figure 15).

In the category of behavioral change intervention, educational prompts have the highest percentage of "somehow important" (41.3%) and "very important" (30.4%) and a low percentage of "not important" (4.3%) and "less important" (5.8%). Table cards (written global/regional/national food waste statistics and its impact on environmental, social, and economics) also have a high percentage of "somehow important" (38%) and "very important" (25.4%), but lightly less important than educational prompts. Post prompts (4.3% and 5.8%) and salient signs (3.6% and 11.2%) have the highest negative percentage of "not important" and "less important".

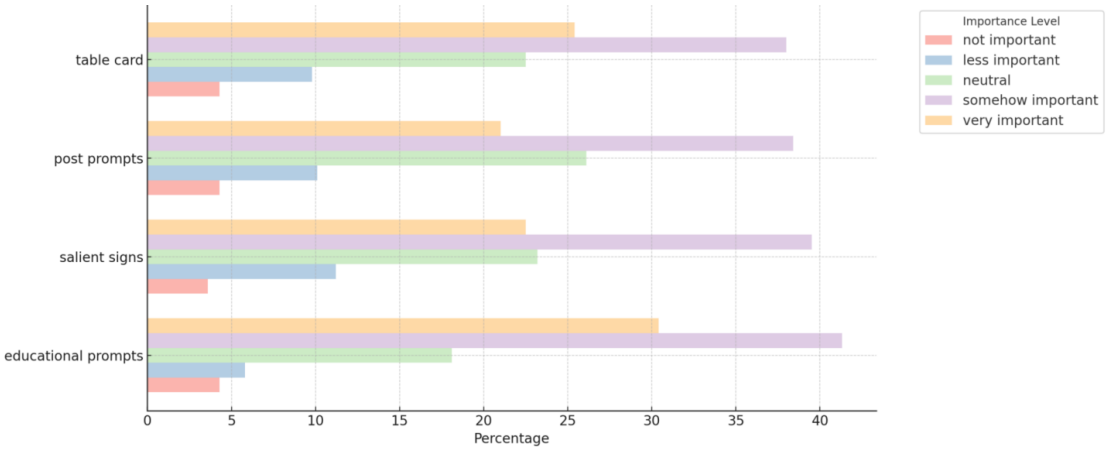

Figure 12 Behavioral-change intervention in canteen, N=276

Source: authors' own construction

When respondents were asked to evaluate the infrastructural interventions in the canteen, they rated the highest "somehow important" (40.6%) of self-service and the highest "very important" (38.4%) of paying as much as you order. However, the method "different portion size" got the highest percentage of positive opinions, "somehow important" (36.2%) and "very important" (36.6%). The lighter important method is providing takeaway options for uneaten food and heating services for leftover food (somehow important: 36.2% and very important: 34.1%). The trayless dining system got the highest negative percentage of "not important" (6.9%) and "very important" (12.7%) and the lowest positive percentage of "somehow important" (34.8%) and "very important" (17%).

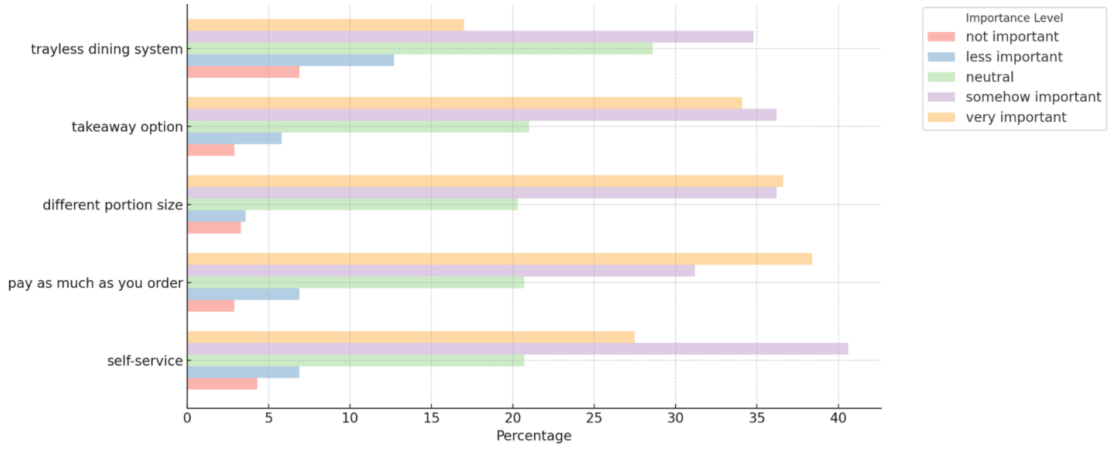

Figure 13 Infrastructural interventions in canteen, N=276

Source: authors' own construction

When it comes to food waste reduction methods at home, using the best refrigerator temperature zones for different food types (44.9%) and cooking the planned amount (43.5%) have the highest percentage of "somehow important." Buying ingredients as a cook needs (33.3%) got the highest percentage of "very" important. Home composting systems (12% and 12%) and food sharing systems with the local community (10.9% and

12.3%) hold the highest negative percentages of "not important" and "less important" and relatively low positive percentages.

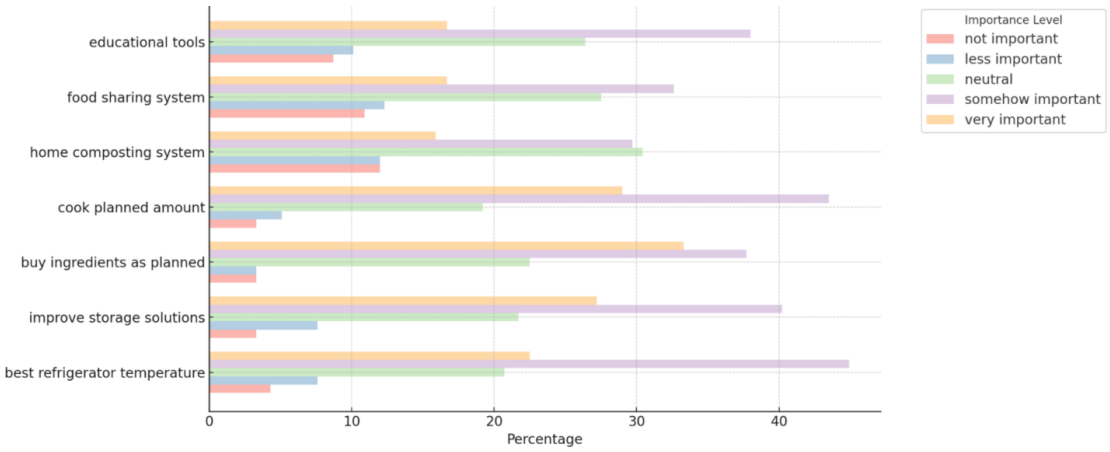

Figure 14 Infrastructure interventions at home, N=276

Source: authors' own construction

Some food waste reduction methods can be used both in the canteen and at home or in the dormitory. Giving it to waste contractors got the highest percentage of "somehow important" (34.4%) and "very important"(21.4%). The lighter important method is giving it to the local council (somehow important: 32.2% and very important: 16.3%). Donating to food banks or homeless shelters got the highest negative percentage of "not important" (15.9%) and "less important"(17.8%). The following are composting (converting food waste to soil fertility) (13% and 17%) and anaerobic (converting food waste to energy, such as electricity and fuel) (13.4% and 17%).

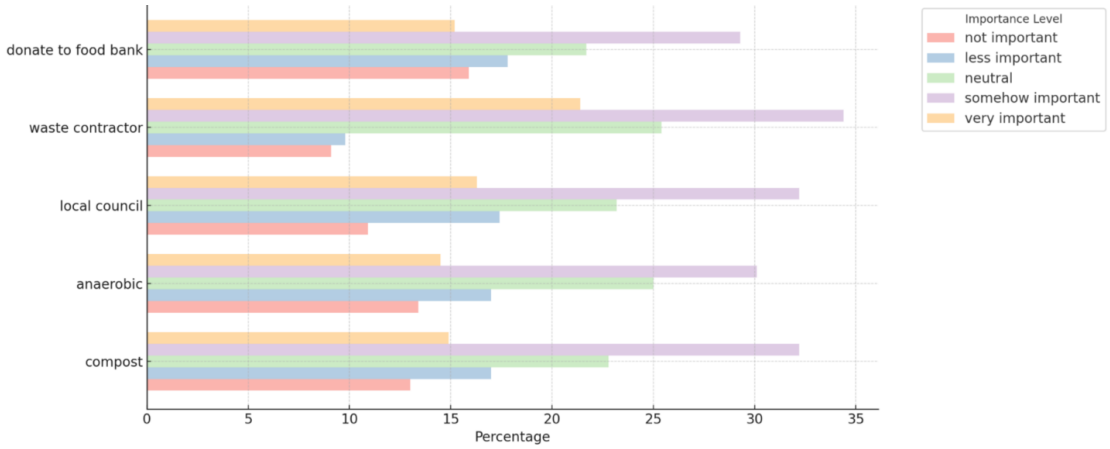

Figure 15 University/company canteen or home/dormitory, N=276

Source: authors' own construction

As mentioned above, it is clear that respondents evaluated the exact strategies in each category. The effective food waste reduction methods can be educational prompts, table

cards (written global/regional/national food waste statistics and its impact on environmental, social, and economics), self-service, paying as much as you order, providing takeaway options for uneaten food and heating services for leftover food, using the best refrigerator temperature zones for different food types, cooking the planned amount, buying ingredients as cook need, giving it to waste contractors, and giving it to the local council. However, some methods seem obviously not practical relatively for respondents, such as post prompts and salient signs, trayless dining systems, home composting systems, food-sharing systems with the local community, Donating to food banks or homeless shelters, composting (converting food waste to soil fertility), and anaerobic (converting food waste to energy, such as electricity and fuel).

These results enhance the depth and clarity of the analysis of food waste reduction strategies, enabling more nuanced and actionable insights. In order to offer a more comprehensive picture of the effectiveness of different category strategies, both the mean and standard deviation were provided (Figure 16). The mean gives an overall assessment, indicating how respondents generally evaluated the food waste reduction strategies. Meanwhile, the standard deviation provides insight into the consistency and reliability of these assessments by showing how much the responses vary around the mean.

The mean and standard deviation chart provides a comprehensive overview of the perceived importance of various food waste reduction strategies, categorized by intervention types. Strategies focused on behavioral-change interventions in the canteen and infrastructural interventions at home tend to be rated highly, indicating strong support from respondents. In general, the given strategies were evaluated carefully by respondents and got their approval as the least mean value is higher than 3, indicating a neutral attitude. And the highest mean value is less than 4, indicating “somehow important.” The standard deviation is represented by the error bars on each bar, indicating the consistency of the evaluation by the length of the error bars. The longer the error bars are, the wider the range of ratings is, indicating varying opinions among respondents and vice versa.

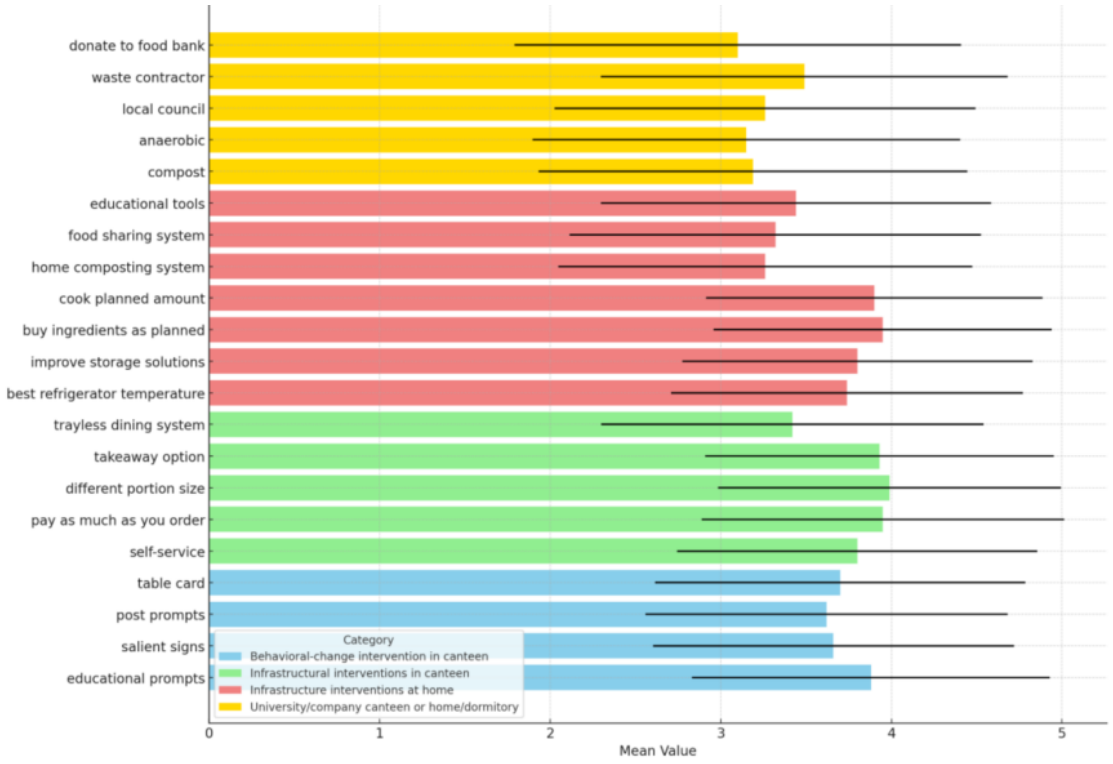

Figure 16 Effectiveness of interventions to reduce food waste by category, N=276

Source: authors' own construction

By considering the mean and standard deviation, salient signs, educational prompts, buying ingredients as planned, cooking the planned amount, and improving storage solutions are rated highly with minimal variability, indicating strong consensus on their importance. Trayless dining systems, different portion sizes, self-service, takeaway options, and post prompts can be considered moderately important strategies as they have moderate mean values and show more variation in opinions, suggesting that while they are important, their effectiveness might depend on specific contexts or individual preferences. However, those strategies that stand out as particularly unimportant based on their low mean values and high standard deviations and respondents generally rated these strategies as less effective, with notable disagreement about their importance, are waste contractor, anaerobic, and local council. There are also some unimportant strategies with low mean values but moderate variation: composting and using the best refrigerator temperature zones for different food types.

4.5.5 Cluster analysis on food waste behavior and sociodemographics, food consumption habits, attitudes, and awareness

The cluster analysis was performed to identify distinct groups within the dataset based on sociodemographics, food consumption habits, attitudes, and food waste behavioral variables. The K-means clustering algorithm was applied, and the convergence of the

clustering process was achieved after eight iterations, with negligible changes in cluster centers, indicating that the algorithm successfully partitioned the dataset into two stable clusters. Cluster 1 has 202 samples, and Cluster 2 has 74 samples. These clusters demonstrate significant differences across various variables, providing meaningful insights into the underlying patterns within the data. The final cluster centers indicated the characteristics of each variable in 2 clusters . The inter-cluster distance between final cluster centers is 3.303, indicating the distinct difference between the 2 clusters. The average distance of data points to their respective cluster centers is relatively low, indicating a high degree of cohesion within each cluster. This tight clustering suggests that the data points are well-represented by their assigned cluster centroids, thereby enhancing the overall validity of the clustering solution. The analysis of variance (ANOVA) results confirmed the statistical significance of several variables in distinguishing between the two clusters (p<0.05).

Cluster 1, named for “frequent food wasters”, is characterized by more often food waste from highly educated females who are younger, living in a city with a high monthly income. This cluster tends to be active students preferring to buy meals in the canteen on normal school days. When they are prone to be non-vegetarian, and consume more bread, rice, noodles, meat, fish, dairy and eggs, fruit, vegetables, and other food types, the most common reason for food waste is clear. This group tends to waste food primarily due to external and emotional factors such as receiving portions that are too large, encountering bad quality food, low prices that may encourage over-purchasing, and unpleasant emotions that might lead to discarding food. Surprisingly, they are usually more confident that they will finish the food when they order. It should be noted that despite the p-value of 0.067, which indicates a non-significant difference at the 0.05 level, age remains an important factor to consider due to its potential impact on the characteristics and behaviors of the clusters and may have a meaningful role.

Cluster 2, named for “conservative food wasters”, comprises relatively rare food waste consumers who are older vegetarian or vegan non-student males living in rural areas with lower education and lower income. Most of the time, they cook at home and consume less often about the food types (bread, rice, noodles, meat, fish, dairy and eggs, fruit, vegetables, and other food types). This group wastes food due to more personal judgment and time management issues. They may not have a clear reason for food waste, find the food not tasty, overestimate the amount of food needed when ordering or cooking, or run

out of time to finish the food. Even though they rarely waste food, they are not confident about finishing the food when they order it. This demonstrates that when consumers are more careful about how much they can eat, they are prone to waste less often.

4.5.6 Decision tree analysis between different dining habits associated with food waste

The overall decision tree model accuracy is 72.8%, indicating that the model has a good predictive ability. The decision tree model was validated through cross-validation, with a cross-validation estimate of 0.333 and standard errors of 0.027 and 0.028. This indicates that the model was reasonably reliable in classifying the dependent variable based on the independent variables. The results of the decision tree were explained by the tree diagram (Figure 17, Table 16). The decision tree has a depth of 3, with a total of 10 nodes and 6 terminal nodes, indicating a moderate level of complexity. The relatively shallow depth helps to prevent overfitting, ensuring that the model remains generalizable. However, this shallowness may also limit the model's ability to capture more intricate or complex patterns in the data. 56.2% (155) of respondents chose to buy meals at the university or company canteen during working days or school days. The rest chose to cook at home or in a dormitory (43.8%, 121), which indicated that the respondents were distributed evenly on two different dining habits. It makes the further decision tree analysis between the two different dining habits associated with food waste behavior meaningful. By revealing the primary determinants of dining habits, effective food waste reduction strategies can be employed on specific occasions. The independent variables include respondents' socio-demographic characteristics, food consumption habits, food waste behavior (frequency and amount), attitude, and awareness. As the tree diagram indicated, the primary determinants of dining habits are respondents' current occupation, monthly income, food waste frequency, and types of meals with more waste.

Level 1 splitting by respondents' "current occupation" gives 84.5% (71) of meals buyers as students, 53% (80) of meals buyers as employed, working while studying, and unemployed, and 90.2% (37) of meals cook on self-employed and retired. It is clear that people who have more flexible time management tend to cook at home, such as those who are self-employed and retired. Studying and working or waiting for work do not allow people to have more free time to cook for themselves and it is reasonable that they prefer to buy meals at the canteen. Out of 71 (84.5%) students who are meal buyers, 90.4% (66) have less monthly income (<4000 yuan), while 54.5% (6) with higher monthly

income (>4000 yuan) cook for themselves at level 2 splitting. Among the majority of the respondents, out of 151 (54.7%) employed, working while studying, or unemployed respondents, 53% (80) of them are meal buyers. At level 2 splitting, 55.9% (57) of employed, working while studying, and unemployed respondents cook at home with rare food waste frequency, while 71.4% (35) of meal buyers have a higher frequency of food waste. 88.9% (16) of employed, working while studying, and unemployed respondents who have more frequent food waste have more food waste in lunch rather than dinner, while 61.3% (19) of them waste more in dinner at level 3 splitting. 31 (11.2%) respondents who are employed, working while studying, or unemployed waste food more often and mainly during dinner, and 18 (6.5%) of them have more waste during lunch. This insight helps to better understand the context in which food waste occurs and highlights specific areas for targeted interventions.

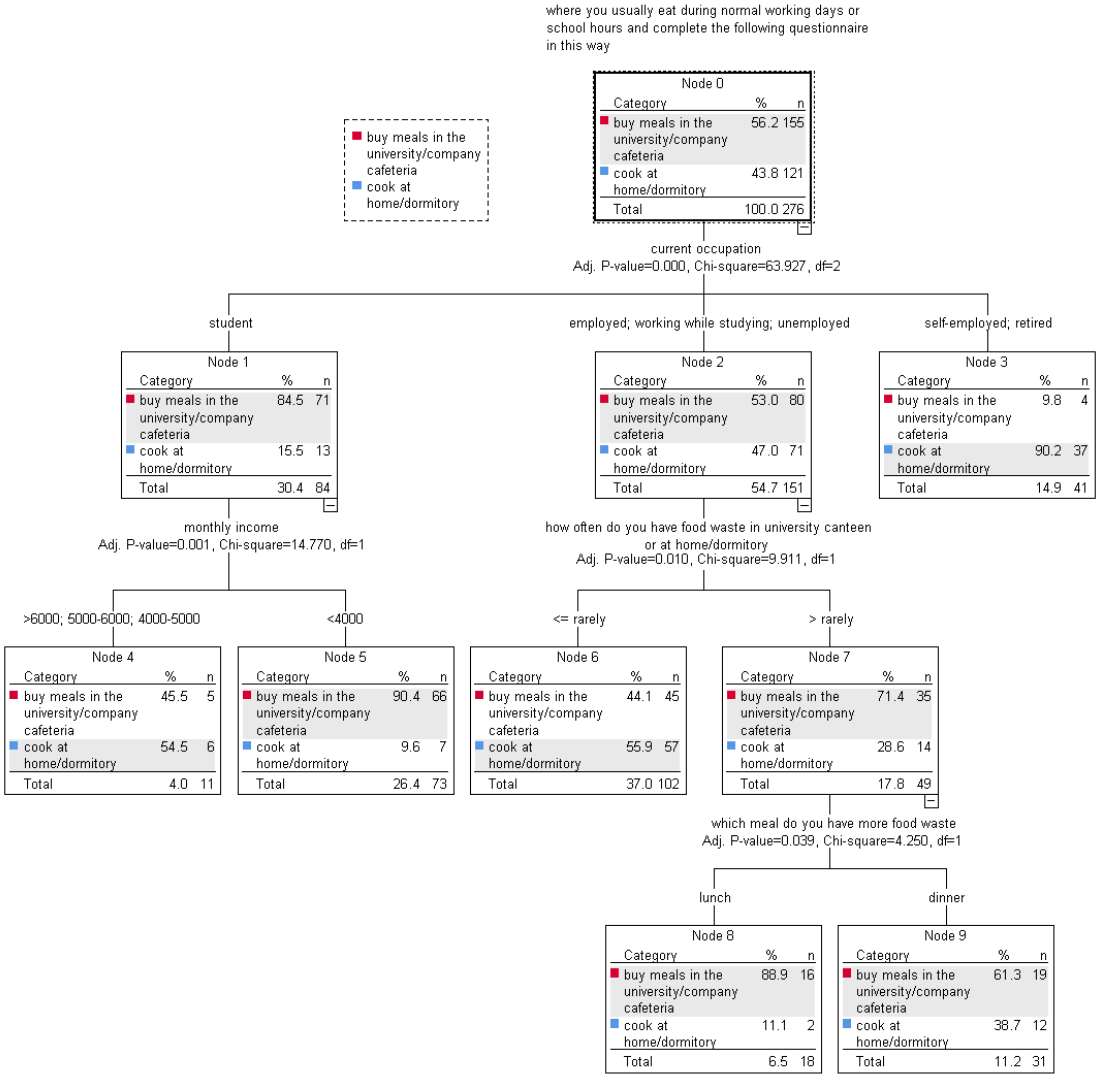

Figure 17 Decision tree diagram of dining habits, N=276
Source: authors' own construction

Table 16 The representation of the decision tree diagram, N=276

Node	Meals buyer	Meals cook	Predicted Category	Parent Node	Variable	Sig.[a]	Split Values
0	155	121	Meals buyer				
1	71	13	Meals buyer	0	current occupation	0.000	student
2	80	71	Meals buyer	0	current occupation	0.000	employed; working while studying; unemployed
3	4	37	Meals cook	0	current occupation	0.000	self-employed; retired
4	5	6	Meals cook	1	monthly income	0.001	>6000; 5000-6000; 4000-5000
5	66	7	Meals buyer	1	monthly income	0.001	<4000
6	45	57	Meals cook	2	food waste frequency	0.010	<= rarely
7	35	14	Meals buyer	2	food waste frequency	0.010	> rarely
8	16	2	Meals buyer	7	which meal do you have more food waste	0.039	lunch
9	19	12	Meals buyer	7	which meal do you have more food waste	0.039	dinner

Source: authors' own construction

In summary, dining habits, either buying meals in the canteen or cooking meals at home or dormitory, are mostly dependent on an individual's personal economic conditions, such as occupation and income, but it is also closely linked with food waste behavior, such as food waste frequency and types of meals with more waste. However, the impact of food waste amount on dining habits can not be found.

4.5.7 Findings from secondary research

Food waste refers to the decrease in quantity and quality of food at the consumption stage across the entire food value chain, such as food service, retail, household [157], and other formats of consumption. However, only the agricultural and breeding products (plants and animals) and their fragments and the final edible food intended to be for human consumption are classified into food loss and food waste.

The causes of FLW were summarized by the Ishikawa model (Figure 18) [158] to better explain the main causes in the whole value chain [159]. The main environmental impact of food loss and waste is at the primary production stage and a large amount of total food loss and waste. The primary reasons for food loss and waste are storage conditions controlling (moisture, temperature, pest damage, microorganisms) and unsuccessful transportation (inadequate raw materials quality and transport conditions). Food industrial processing is a heavy and large industrial activity, including food industrial facility design, technical safety, food processing materials safety, occupational safety and health, fire protection and electricity safety, and environmental protection. A safe food industrial processing can not only assure the development of economies and businesses and optimizing the use of opportunities from the perspectives of increasing food quality and safety, saving energy and natural resources, and reducing food waste and environmental burdens, but also a source for achieving sustainable agriculture and food [160].

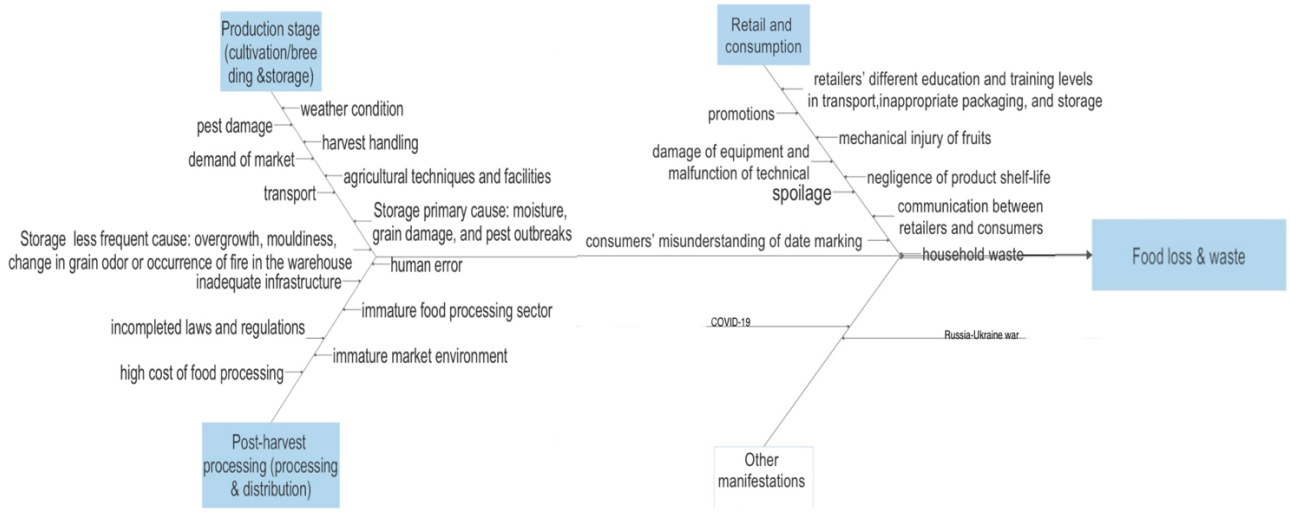

Figure 18 Causes of food loss and waste

Source: author's own construction

It was concluded three dimensions [161] to reduce food loss and waste from enhancing digital education on reducing food loss and waste to all the actors in the food chain, investing in research or collaborative research on understanding and reducing food loss and waste, and appealing to governments and policymakers to build legislative and non-legislative initiatives on reducing food loss and waste to accelerate agriculture transition to more resilient and sustainable mode. The sustainable path tackling FLW can be from two viewpoints: across the agriculture value chain (at the agricultural production and storage stage, post-harvest processing stage, transform food waste into high-value-added products, extending products' shelf life, and innovative selling methods) and the public and individual (strengthen policy and education investment, and increasing consumers' consciousness on reducing food waste) [162].

4.6 Justification of the hypothesis in the thesis

All of the thesis hypotheses were justified based on secondary research and primary research (Table 17).

Table 17 Justification of theis hypothesis

Research hypothesis	Research results justification the hypothesis	Numbering and topic of the results
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.	√	4.1 Food security crisis 4.2 The necessity of sustainability
H2: Awareness is crucial to ensure food security, and the most effective way to raise awareness is education.	√	4.3 The crucial role of education in increasing global citizens' awareness to ensure sustainable food security
H3: Sustainability is necessary to ensure food security and green food is getting more and more welcomed by consumers.	√	4.2 The necessity of sustainability
H4: Farmers play a crucial role in food supply at the production stage and utilizing digital agricultural technologies to improve food production.	√	4.4 Farmers' role in ensuring food security from the perspective of digital agricultural production
H5: Food loss and waste are the biggest risk threatening food security, but everyone can contribute to reducing food waste.	√	4.5 Individual responsibility in ensuring food security from the perspective of food waste reduction

Source: author's own construction, $N_{CS\ 2.}$=581 (2021), $N_{CS\ 3.}$=328 (2024), $N_{CS\ 4.}$=5 (2024), $N_{CS\ 5.}$=276 (2024)

5 DISCUSSION

The synthesis results of the thesis work, including primary research and secondary research, were discussed and compared to the literature in this chapter. The research findings can serve as a foundational basis for policy-making and provide empirical data to support initiatives [163]. Both descriptive and explorative studies contributed to the paths to sustainable food security and offered valuable baseline data by providing detailed observations and descriptions that are necessary for the development of theories and models.

To achieve the research aims, various theories and methodologies were used in secondary research and primary research to answer the research questions (Table 18).

Table 18 Summary of used theories and methodologies to answer the research questions

Research aims	Research questions	Hypothesis	Used theories in case study	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 • Roger's Diffusion of Innovation Theory – CS 1. CS 2.	• Cronbach's α analysis • 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 3.	• Cronbach's α analysis • Chi-square analysis • Pearson correlation analysis • 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 shot of sustainable agriculture in ensuring food security? 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 -CS 2.	• Content analysis • Spearman correlation analysis • 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 4.	• Thematic Analysis • Pearson correlation analysis
	Q5. What is the shot 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 5.	• Cronbach's α analysis • Pearson correlation analysis • Ordinal logistic regression analysis • Cluster analysis • Decision tree analysis
	Q6. What is the role of every global citizen in food loss and waste?			

Source: author's own construction, $N_{CS\,2.}$=581 (2021), $N_{CS\,3.}$=328 (2024), $N_{CS\,4.}$=5 (2024), $N_{CS\,5.}$=276 (2024)

5.1.1 Food security crisis and the necessity of sustainability

In light of the global view, the most agricultural risks and threats trends are related to it, such as globalization, demographics and security, natural risks, health security, limit of resources [164], international system of governments, environmental security, and biodiversity (climate change or extreme weather [165]), energy and infrastructure security. Additionally, the future agricultural production and demand, obstacles of irresistible digital agriculture [18], security issues in agriculture 4.0 [72], [166], market fluctuations [167], [168], and food security issues (food loss and waste) [169], [170] are also under agricultural risks and threats trend. The other two points, which are temporary influencing factors in agriculture but not trends, belong to the global security change and trend category, natural risks (COVID-19 [171],112 and post-cold war security characteristics (Russia-Ukraine war [165]). Meanwhile, sustainable, healthy, or green food purchase patterns are getting more and more popular, such as organic food (especially organic fruits and vegetables), even in different countries adopting stages (eg. Hungary and China) [76].

5.1.2 The crucial role of education in increasing individual's awareness to ensure sustainable food security

In this thesis, it is found and highlighted that education is important in realizing sustainable agriculture and sustainable food security. For instance, strengthening education for individuals eating outside or at home on circular economy and good eating habits is helpful to reduce food waste [163], and there are many common education measurements, such as information campaigns and social media [172].

5.1.3 Farmers' role in ensuring food security from the perspective of digital agricultural production

Even though the benefits of digital technologies in agricultural production are promising, and the opportunities to realize sustainable development goals are high, the factors hindering farmers from adopting digital technologies are complex. Different researchers summarized it from different perspectives, and the most common viewpoint is from agroecological factors, technological factors, institutional factors, psychological and behavioral factors, and other individual farmer characteristics [173].

5.1.4 Individual responsibility in ensuring food security from the perspective of food waste reduction

Food loss and waste include qualitative and quantitative perspectives along the food supply chain at all the stages [174], including the primary or agricultural production, sorting and grading to meet retailer standards [26],[174], processing and storage [175], huge waste in households [26], and waste due to date labeling misunderstanding [176]. Food loss and waste are not distributed equally in the value chain steps [86] and in different countries. Plate waste is a very common problem in China's university canteens [115]. Food waste behavior results from various characteristic [94]. Ethical level [178], [179] and personal lifestyle (people are lack nutritional knowledge or used to purchasing and overstock food) [180], [181] are the important cause of food waste and food waste at the consumption stage, but which is a lack of enough research, how to improve consumers' awareness and ethical level and change current lifestyle where food loss and waste from reducing food loss and waste is still a promising research agenda.

Three dimensions to reduce food loss and waste were suggested: enhancing digital education on reducing food loss and waste to all the actors in the food chain [14], [27], [182], [183], [184], [185], investing in research or collaborative research on understanding and reducing food loss and waste [174], [185], [186], [187], [188], and appeal governments and policymakers to build legislative and non-legislative initiatives on reducing food loss and waste to accelerate agriculture transition to more resilient and sustainable mode [26], [174], [185], [186], [189], [190], [191].

6 SUMMARY CONCLUSIONS

Based on the six research questions mentioned, I aimed to deal with three thesis aims: examine the food security crisis situation, explore the crucial role of education in increasing individual awareness to ensure sustainable food security, and identify farmers' and food consumers' roles across the food value chain to contribute sustainable food security after the massive literature study and four primary research investigation. In this chapter, the concluding remarks of the entire thesis work and recommendations for future research were provided.

6.1 Concluding remarks

At the beginning of the thesis work, I researched the food security crisis by identifying the risks and threats in agriculture, which, together with the topic of food consumption changes, proved the necessity of sustainability.

Further on, the role of education in increasing individual awareness to ensure sustainable food security was proved, especially the early education about DAT, food waste, and food security are highlighted as important to raise awareness. Individual awareness of food safety and food security are closely linked. The group "food safety-unaware" (more likely younger students with lower salaries and lower degrees) and the group "food security ignorant" (more likely younger rural residents with significantly lower education levels and lower monthly income) should be given more education to strengthen food safety and food security awareness. The traditional solutions, such as government intervention and early education, are efficient in improving individual awareness of food safety and food security. While, emerging methods, such as digital games and influencer outreach, should be considered carefully before utilization.

The two most important players across the food value chain were identified through the value chain study: farmers from the production stage and individuals from the consumption stage. Their roles were regarded as the direct solutions to ensure sustainable food security. The adoption of digital agricultural production technologies is the key tool to produce food yields, improve production efficiency and quality, and, at the same time, reduce the negative impact on the environment. An individual's food consumption behavior directly impacts food security, such as food waste.

Farmers' perceptions can improve the adoption of DAT on DAT. Limited market availability, half-automated application, immature operation, lack of knowledge, aging

workforce, and compatibility issues with small-scale operations restrict the adoption of DAT at an early stage in Bayannur, China. It is positive for both traditional and "new" farmers to adopt DAT in this region, and the perception of DAT varies from male to female significantly. To address the development of DAT in Bayannur, the aging workforce and the prevalence of small-scale lands or plants are the biggest challenges to conquer. They believe in the crucial role of governmental interventions and early education. DAT sharing or collaborative systems seem to be more practical for the current stage, and they wish to get more in-person training about DAT.

Individual food waste behavior can imply efficient strategies to reduce food waste. The frequency and amount of food waste are significantly associated. Two dining habits, meal buying and cooking at home, manifest different food waste behaviors. Demographic factors have a significant relationship with food waste behavior. For instance, education level and gender may influence food waste frequency, and student status and faculty may influence food waste amount. Meal preparation habits may influence food waste frequency, but not significantly at the conventional alpha level. Respondents waste food mainly because "ordered or cooked too much than estimation", "the unit served portion size is too big" and "Bad food quality". Behavioral-change interventions and infrastructural interventions should be made for the group "frequent food wasters" (more likely higher educated females who are younger, living in a city with a high monthly income).

6.2 Limitations and future research recommendations

First of all, the method and structure of this thesis about the paths to sustainable food security can be used to analyze other countries or regions besides China. The detailed methodology outlined in this thesis provides a blueprint for future researchers to replicate similar interventions. Further on, comparative studies can be conducted based on the same research methodology.

In addition to the research methodology, some topics derived from the entire thesis that are not discussed or not discussed in-depth can be valuable to support food security topics. For instance:

1. A comparative study between the real main crop export quantity and the prediction for the period of 2022-2024 can explain how the Russia-Ukraine war impacts on world food supply.
2. The challenges and measurements of digital agricultural education can be

researched to provide more suggestions for adopting digital solutions in agricultural production.

3. Studies or reports related to security problems or issues of digital technologies used in agriculture can provide suggestions for corresponding policy-making and better utilization, such as 5G or GPS.
4. Due to time and labor constraints in this thesis work, I was unable to employ the direct weighing method, which is considered more objective, accurate, and reliable for investigating food waste [192]. Evaluating food waste by weighing methods and photographic combined self-reported methods to investigate food waste [32] and researching the reduction measurements or technologies in specific regions can encourage individuals to reduce food waste from daily life.
5. Even though the focus of the thesis research is farmers and consumers, the sample covered all five important roles across the food value chain. However, the number of responses from transporters, food processors or handlers, and retailers is small, and there is not enough literature to study the awareness level of food processors or food handlers.
6. Risk analysis and potential mitigation solutions of the adoption of emerging digital agricultural technologies can help to better use it, such as quantum machine learning in crop disease detection systems.

It should be noted that due to the sampling method limitations, some of the thesis results might not be able to represent the entire population in China but instead the specific region, such as agricultural practitioners' risk perception in Bayannur.

NEW SCIENTIFIC RESULTS AND RESEARCH CONTRIBUTION

1st thesis point: Food Security Triangle Model

Before demonstrating the new scientific results of this thesis, I passionately put forward the research model, "Food Security Triangle Model" (Figure 19), 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 make sure "producing more" from farmers and "waste less" from individuals, the awareness and knowledge of food safety and food security are playing a crucial role.

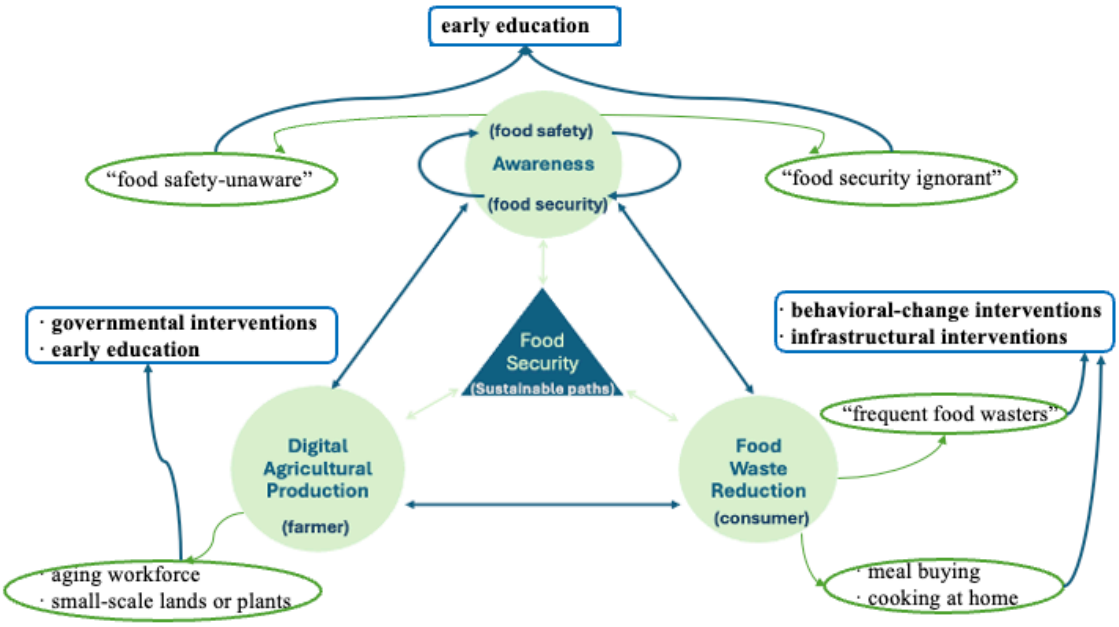

Figure 19 Food Security Triangle Model

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: Food security crisis and the necessity of sustainability

Risks and threats in agriculture should be taken care of as important as global security changes and trends, which are not just vital for individuals but for a nation's security. The Russia-Ukraine war will depress the world's food security after COVID-19. For the time period of 2022-2024, Russia and Ukraine will be crucial world food suppliers for main crop products, such as wheat, maize, barley, and sunflower seed. Unfortunately, these two important world food supply countries are still in a long-term conflict, pushing global food security into a worse situation. China will also play an important role in the world's sunflower seed supply for the world. Meanwhile, digital technologies are promising for sustainable agriculture production, and sustainable food products are getting more and more popular among the Chinese, such as organic food.

Related articles to the second thesis point:

Wu, Y. 2022 [141]; **Wu, Y**., Babos, T., & Takács-György, K. 2023a [140]; **Wu, Y**., Babos, T., & Takács-György, K. 2024a [139]; **Wu, Y**., Hanka, L., & Takács-György, K. 2023b [142]; **Wu, Y**., Hanka, L., & Takács-György, K. 2024b [134]; **Wu, Y**., & Takács-György, K. 2022 [143].

3rd thesis point: The crucial role of education in increasing individual's awareness to ensure sustainable food security

Awareness of the five main important players across the food value chain on food safety and food security are interrelated because individuals who are knowledgeable about food security tend to also be knowledgeable about food safety. There is a significant gap between awareness and practice, which means they have weak awareness of food safety and food security, but they have good practice in both aspects. Respondents think the biggest responsible role for food safety and food security in the food value chain is direct food operation involvers, such as food processors and food service staff.

The Chinese respondents' occupation, monthly income, religion, food habit, and their role in the food value chain have significant associations with their perception of food safety, but their highest education may have a marginal impact. The respondents are clustered into "food safety-conscious" and "food safety-unaware" with features of age,

residence area, occupation, income, and highest education. Cluster 1 is formed by members who are relatively older, living in the city, employed, with better salaries and higher degrees. Vice versa, in Cluster 2, members are more likely younger students with lower salaries and lower degrees. There are no significantly different socio-demographic characteristics among clusters. The Chinese respondents are clustered into "food security ignorant" and "food security aware" with distinguished characteristics of age, education, occupation, and income. Cluster 1, "food security ignorant", is formed by younger rural residents with significantly lower education levels and lower monthly income, and there is a significant number of them are students. In contrast, Cluster 2, "food security aware", are older city residents with significantly higher education levels and higher incomes, and employed is a significant occupation. Education, current occupation, and monthly income are significantly different characteristics among clusters.

The marked favoring of effective strategies to raise individuals' awareness of food safety and food security are the same. The traditional methods, such as government intervention and early education, are the most important solutions, and "the role of youth in contributing as global citizens" and "education and training in transforming knowledge into daily practice" are less important. Meanwhile, newer strategies, like digital games and influencer outreach, prompted more varied responses and showed less overall enthusiasm.

Related articles to the third thesis point:

Pál, B., **Wu, Y**., & Takács-György, K. 2023 [147]; **Wu, Y**. 2022 [148]; **Wu, Y**., Pál, B., & Takács-György, K. 2024 [144]; **Wu, Y**., & Zhong, X. 2022 [146]; Zhong, X., & **Wu, Y**. 2022 [147].

4th thesis point: Farmers' role in ensuring food security from the perspective of digital agricultural production

The adoption of DAT in Bayannur is in an early stage, primarily due to factors like limited market availability, half-automated application, immature operation, lack of knowledge, aging workforce, and compatibility issues with small-scale operations, where high cost was not regarded as a significant issue. Even though DAT adoption varies between traditional and younger farmers (more business-oriented thinking and ability to keep updated about DAT knowledge), both of them view it proactively as a pathway to more efficient and scientific farming practices. The utilization of DAT is supported by families

and communities of the main decision-makers, and women seem to have significantly different opinions.

The biggest barriers to adopting DAT in Bayannur are the aging workforce and the prevalence of small-scale lands or plants. Governmental policies play a crucial role in facilitating DAT, especially through land transfer policy, export incentives, and organized training initiatives. Besides, in-person training about DAT is also seen as an effective way to improve DAT knowledge over online forms. DAT sharing or collaborative systems are more affordable and practical for traditional and new farmers. Early education about DAT, food waste, and food security are highlighted as important to raise awareness.

Related articles to the fourth thesis point:

Vuka, E., & **Wu, Y**. 2024 [156]; **Wu, Y**. 2022 [151]; **Wu, Y**., & Liu, Y. 2022 [152]; **Wu, Y**., & Rajnai, Z. 2024 [153]; **Wu, Y**., & Takács-György, K. 2023 [150]; **Wu, Y**., & Takacs-Gyorgy, K. 2023 [155]; **Wu, Y**., & Zhong, X. 2022 [96]; **Wu, Y**., Zhong, X., & Takács-György, K. 2023 [149].

5th thesis point: Individual responsibility in ensuring food security from the perspective of food waste reduction

Food waste is quite a common phenomenon among the investigated Chinese people. Food waste behavior was demonstrated as food waste frequency and amount, and these two aspects are closely associated. Food waste behavior is impacted significantly by demographic characteristics, consumption habits, food waste awareness, knowledge, and attitude. Food waste frequency is negatively impacted by age, religion, perception of the food waste problem, and awareness of economic benefits (increased profit) of reducing food waste, and positively impacted by bread consumption, understanding of UN/EU definition of food waste, awareness of social benefits (improve reputation) of reducing food waste, meal satisfaction, and confidence to finish plate. Food waste amount is negatively impacted by city residents, religion, buying meals, consuming rice, noodles, fish, and others, perceiving food waste as an ethical issue, perception of food waste problem, awareness of environmental benefits of reducing food waste (conserving precious energy and resources), lunch and fresh food, and positively impacted by age, rural residences, income, consuming meat, dairy and egg, and vegetables, purchasing snacks, perception of Chinese definition of food waste, perception of food waste as food security issue, environmental benefits (reducing the canteen's negative impact on the

environment) and economic (saving money from thrown away food) of reducing food waste, dinner, weekend, cooked meals and satisfaction with meals. The positive relationship indicated that as the predictor increases, the dependent variable will also increase, and vice versa. For instance, when respondents consume more bread, the frequency of their food waste behavior could also increase. As age increases, the frequency of food waste frequency could decrease.

The reasons for wasting food mainly are “ordered or cooked too much than estimation”, “the unit served portion size is too big” and “Bad food quality”. Some behavioral-change interventions in the canteen, infrastructural interventions in the canteen, at home, and university/company canteen or home/dormitory can effectively reduce food waste. The best solutions to reduce food waste can be salient signs, educational prompts, buying ingredients as planned, cooking the planned amount, and improving storage. The moderate strategies are trayless dining systems, different portion sizes, self-service, takeaway options, and post prompts. Some strategies should be neglected, such as waste contractors, anaerobic, and local councils. There are also some controversial strategies, such as composting and using the best refrigerator temperature zones for different food types.

The respondents were clustered into “frequent food wasters” and “conservative food wasters” with features of different age, highest education, gender, city or rural residence, monthly income, dining habits, vegetarian or non-vegetarian or vegan, food consumption pattern, food waste reason, and confidence to finish plate before ordering. The decision tree analysis reveals that dining habits (meal buying vs. cooking at home) are shaped by an individual’s personal economic conditions, such as occupation and income, but it is also closely linked with food waste behavior, such as food waste frequency and types of meals with more waste.

Related articles to the fourth thesis point:

Wu, Y., & Nagy, R. 2022 [160]; **Wu, Y.**, & Takács-György, K. 2023a [159]; **Wu, Y.**, & Takács-György, K. 2023b [162]; **Wu, Y.**, & Takács-György. 2023 [161].

LIST OF PUBLICATION

Articles related to this thesis

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. 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.
4. **Y. W**u, "Mobile Communication Evolution and the development of 5G in China," HÍRVILLÁM = SIGNAL BADGE, vol. 2024, no. 1, pp. 167–178, 2024.
5. **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.
6. **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.
7. **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.
8. 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.
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LIST OF ABBREVIATIONS

Case study – CS

Circulation (transfer) of Rural Land Contracting and Management Rights (CRLCMR)

Climate-Smart Agriculture (CSA)

Digital Agricultural Education (DAE)

Digital agricultural technologies (DAT)

Digital agriculture education (DAE)

Food loss and waste (FLW)

knowledge, attitudes, and practices (KAP)

Sustainable Development Golas (SDGs)

Technology Acceptance Model (TAM)

Thematic Analysis (TA)

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APPENDIX. STATISTICS ANALYSIS

Cronbach's α analysis

Cronbach's α analysis technique was employed to examine the reliability of the survey using the Alpha model. If $\alpha > 0.9$, the questionnaire has excellent internal consistency; 0.8-0.9: good consistency; 0.7-0.8: acceptable consistency; 0.6-0.7: questionable consistency; and if $\alpha < 0.6$, the questionnaire has poor consistency, suggesting the need to revise the scale.

Correlation analysis

The Chi-square analysis (category variables) gave Pearson's Chi-Square value, degrees of freedom (df), and p-value. The p-value was much higher than the typical threshold of 0.05 (there is no association between the two variables), which means the null hypothesis cannot be rejected. In simpler terms, this suggests that there isn't a significant association between the two variables being tested, and any differences observed are likely due to random chance rather than a real relationship. The correlation analysis between food waste frequency and the possible causes (subchapter 4.5), such as demographic characteristics, food consumption habits, food waste knowledge, and awareness, was conducted by Chi-square analysis and Spearman's analysis according to whether the variables are nominal or ordinal.

Pearson correlation analysis was employed to explore the correlations between ordinal variables. The Pearson correlation coefficient (r) ranges from -1 to 1, reflecting both the direction and strength of the relationship between the two variables. A positive value indicates that as one variable increases, the other tends to increase as well and vice versa. The strength of the correlation can be categorized as very weak (0 to ±0.1), weak (±0.1 to ±0.3), moderate (±0.3 to ±0.5), strong (±0.5 to ±0.7), or very strong (±0.7 to ±1.0). The p-value (Sig. (2-tailed)) was examined to determine the statistical significance of the correlation. A p-value less than 0.05 typically indicates that the correlation is statistically significant, a p-value below 0.01 signifies a highly significant correlation, whereas a p-value above 0.05 suggests that the correlation is not statistically significant. The significant p-values confirm that these relationships are statistically significant, meaning the observed correlations are reliable and not due to random chance.

Ordinal logistic regression analysis

Ordinal logistic regression analysis was performed between food waste behavior (frequency or amount) and demographic characteristics, attitude, knowledge, and food consumption habits to examine the strength of their relationship. The proportional odds model, a constrained cumulative logit model, is the most commonly utilized ordinal logistic regression model in practice [193], [194]. In order to ensure the robustness and reliability of the results, a maximum iteration of 100, a maximum of five step-halvings, a log-likelihood convergence set to 0, a parameter convergence criterion of 0.000001, and a singularity tolerance of 0.00000001; the 95% confidence intervals for parameter estimates and the Logit link function were optimized, with no delta for gradient estimation. Predictor variables that demonstrated a statistically significant bivariate relationship (p <0.05) with self-reported food waste behavior were included in the ordinal logistic regression analysis. The goodness-of-fit test determines if the model fits the data well. It suggests a good fit when the p-value is greater than 0.05. Pseudo R-Square (Cox and Snell, Nagelkerke, and McFadden values) indicates the proportion of variance explained by the model. Higher values suggest a better fit. The test of Parallel Lines checks the proportional odds assumption for the ordinal logistic regression model (p>0.05 indicates supports the use of the model). In the parameter estimates, the p-value is less than 0.05, indicating individual predictors' significance.

Cluster analysis

In cluster analysis, the primary objective is to group data points based on their inherent similarities, aiming to minimize variance within clusters while maximizing variance between clusters. To ensure that features are on a comparable scale prior to clustering, z-score normalization is commonly employed. This normalization technique adjusts each feature by subtracting its mean and dividing by its standard deviation, thereby standardizing the data and ensuring that the different scales of measurement did not unduly influence the results. The non-hierarchical K-means cluster method was used to group respondents into different groups after the variables were standardized. In the final cluster center results, the z-score of different values represents the distribution of the variable to mean value: z-score = 0: the data point is exactly at the mean of the dataset; z-score > 0: the data point is above the mean and the larger the positive z-score, the further the data point is from the mean; z-score <0: the data point is below the mean and the more negative the z-score, the further the data point is from the mean. After performing cluster analysis, ANOVA was applied to assess the significance of differences in the mean scores

of the variables between the identified clusters statistically. The differences between clusters are statistically significant at the 0.05 level ($p < 0.05$). This means there is a very low probability that the observed differences occurred by chance. A demographic analysis was performed after validating the clusters to explore the characteristics of each cluster. This Chi-Square tests was used to assess whether there is a statistically significant association between cluster membership and categorical demographic characteristics.

Decision tree analysis

Decision tree analysis was utilized in the thesis to reveal the association between different dining habits regarding food waste behavior. The Exhaustive Chi-square Automatic Interaction Detector (CHAID) was used to split the algorithm [195]. This method was chosen due to its ability to identify significant differences across various independent variables and to segment the data in a visually interpretable manner.

Thematic Analysis based on the Technology Acceptance Model

Agricultural practitioners' perception of DAT was researched by thematic analysis (TA) based on the Technology Acceptance Model (TAM) theory in subchapter 4.4. TA was used to identify, analyze, and report themes or patterns of the research data, which can accurately interpret and present the complex data. Manual analysis was adopted to gain a deeper understanding of the topic, as the process involves extensive interaction with the text instead of using software. The data analysis order is transcription, coding, and analysis.

In order to avoid the bias from the TAM due to its simplicity, respondents' demographic characteristics and their risk perception were taken into account. The TAM proposed by Davis (1989) [196] is among the most commonly utilized frameworks in the study of innovation acceptance. The Technology Acceptance Model (TAM) posits that the actual use of an innovation for an individual is directly or indirectly influenced by a user's intention to use it, their attitude towards the innovation, as well as their perceptions of its usefulness and ease of use.

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