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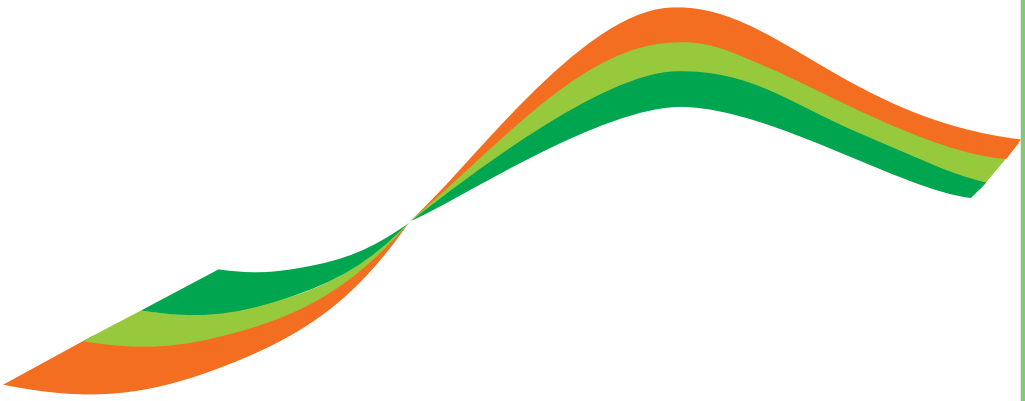

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ECONOMIA AGRO-ALIMENTARE
Food Economy

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FrancoAngeli

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Sustainable Food Supply Chains in Maritime Ports: A Review Across Management, Economic, and Social Dimensions

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Abstract

The growing pressures on the global food supply chain highlight the challenges faced by maritime ports, which are responsible for 80% of global trade, emphasising the need for sustainable operations across management, economic, and social dimensions. This article analyses the research trends in this area within the Scopus database, which was researched on July 11, 2024. The PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) was applied. Based on the results of the systematic literature review, four main subjects were the focus of the researchers: i) smart port requirements and sustainable performance; ii) the technological innovations driving sustainable supply chain management; iii) circular economy and digital supply chain sustainability; iv) frameworks and models for integrating sustainable digital supply chain. Additionally it opens possibility for future research could cover the gaps identified in this article, such as analyzing the effects of Technologies like Artificial Intelligence, Blockchain, and the Internet of Things on the efficiency and environmental goals of ports, evaluating social sustainability in the supply chain through indicators like child labor, rural poverty traps, and standards of living, and food economy. The findings contribute to the academic understanding of sustainable

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development in maritime ports, considering the interconnections among business, economic, and social factors, establishing the groundwork for key performance indicators (KPIs) and opening perspectives for practical innovation.

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1. Introduction

The challenging complexity of modern global food trade, combined with evolving societal expectations, has brought significant challenges to traditional port operations and supply chains (Notteboom *et al.*, 2022). The response to them revealed the need for real-time data-driven decision-making solutions. In response, the concept of smart ports has emerged, integrating digital technologies, automation, and sustainability principles to increase the efficiency, transparency, and resilience of food supply chains in maritime Ports (Cacho *et al.*, 2021). The business environment and the new digital transformation era add their share on top of other pressures from the global supply chain to ports (Fainshtein *et al.*, 2024).

All in all, they need to be smarter, which means being open to adopting new technologies. Smart ports is a topic in this area that has led to the work of several researchers. Despite previous studies that have separately analysed the needs of smart ports, there is still no comprehensive vision on interconnections among business, economic, and social factors, describing various all-encompassing characteristics and a consequent sustainability performance outlook for commercially significant factors in port realms.

The central research question guiding this study is: What are the directions of the research, prospective and retrospective, in the field of Sustainable Supply Chain Management? The article is structured as follows: an introductory part, which sets the context and outlines the research question, followed by section 2, which presents a theoretical framework reflecting the main topics of the study. Section 3 presents the methodology used to produce the article. Section 4 presents and discusses the results. Finally, section 5 presents the conclusion, the limitations and suggestions for future research.

The main direction simultaneously improves desirable economic-social natural indicators, while the aim of this review is to synthesise existing knowledge on sustainable food supply chains in port environments, with a particular focus on management practices, economic feasibility, and social impacts, thereby contributing to both academic discourse and practical innovation.

2. Background

According to UNCTAD - United Nations Conference on Trade and Development (2023), more than 80% of global merchandise trade, including food, is carried out by sea. The maritime port sector represents a strategic industrial zone due to its significant role in modern society and the vast range of business activities it entails (González *et al*., 2020). For example, Batte *et al*. (2020) point out that small increases in profit in this sector can have a great impact due to the number of operations developed at maritime ports. A new integrated concept has arisen, namely that of smart ports, which is expected to support all active ports so they can evolve and be sustainable for existing and future User Ports (Botti *et al*., 2017). On the other hand, according to Yeo (2017), a smart port is defined as possessing automation and high productivity – which must be built on a green system of all port operations, structures, and different means for logistics equipment systems, as well as other logistic infrastructures (Buiza-Camacho-Camacho *et al*., 2016). More simply, a smart port is characterized by improvements in operations (efficiency), energy management, and environmental considerations. Port services will move forward, becoming more interactive and efficient through technologies such as artificial intelligence, blockchain, and the Internet of Things, which are fundamental to realising the sustainability goals for port development (Jun *et al*., 2018).

From a practical perspective, several ports worldwide already present very satisfactory levels of digitalisation – and hence, a sustainable supply chain. Ports such as Hamburg, Antwerp-Bruges, Singapore, Rotterdam, Shanghai, Los Angeles, and Long Beach are seen to incorporate the most advanced supply chains in the world. The NEXUS project aims to bring other ports connected to the Mediterranean region up to a similar level of sustainable supply chain. In this context, the NEXUS project addresses the urgent need for more sustainable food supply chains within maritime ports by promoting, among others, a systemic and multidisciplinary understanding of how economic, social, and management factors interact. This initiative, with a funding of approximately 92 million euros, aims to acquire new knowledge about the sustainability and digitalisation of maritime ports connected to the Portuguese deep-water Port of Sines, which is positioned as the "Atlantic gateway to Europe." The NEXUS project has laid the groundwork for this article, as it profoundly impacts sustainable supply chain management.

The project also seeks to elevate food supply chains in maritime ports to a higher level of competitiveness and global readiness. It aims to provide original products and services to other ports based on a predefined business model, allowing them to achieve similar advancements for a fee. The pressing need for new knowledge in sustainable supply chain management became

clear during project development, and this literature review directly responds to that necessity.

3. Materials and Methods

The article adopted a version of a systematic literature review method proposed by (Denyer and Tranfield, 2009), including a selection of articles. It followed the processes outlined by (Tranfield *et al*., 2003), which comprises three distinct stages:

- Stage 1: Definition of the research purpose and research question.
- Stage 2: Identification of relevant literature, according to established inclusion and exclusion criteria.
- Stage 3: Reporting and dissemination of results.

The definition of the research intention (Stage 1) was previously established in the Introduction section above, while this section aims to clarify the approach adopted in Stage 2. The next section of this article explores Stage 3, which refers to analysing and exploring the relevant data.

The research question was answered by selecting relevant studies significant to the topic. The search was conducted in one database, Scopus. Search terms were established according to the research topic and organised into a search sequence, which allows for greater interaction and reorganisation in the process (Pittaway *et al*., 2004). This resulted in the following sequence: "supply chain" AND "sustainability" AND "indicators" AND "digital*". These keywords were selected because of their relevance to the research topic and, as key performance indicators (KPIs) (especially for maritime ports), constitute a research gap in the literature, as the subsequent research also showed. Let it be noted that this study is being performed in conjunction with the NEXUS project, which involves the digitalisation of maritime ports and their supply chain for added sustainability. This digitalisation is also a question of survival, amidst intense competition for business, as well as for security reasons in an increasingly uncertain world. Maritime ports in times of peace and stability represent a major channel for goods to enter and exit a country. In other more turbulent times maritime ports take on an even stronger responsibility. The research was conducted in the Scopus database on July 11, 2024. Other reviews were also included in the analysis due to the dearth of articles and publications found in the original research effort.

Results were limited to the subject areas "Business, Management and Accounting,"; "Economics, Econometrics and Finance; and "Social Sciences" based on a preliminary analysis of the existing literature on sustainable supply chains in ports, as well as the multidisciplinary nature of the

subject. These three domains capture the key dimensions involved in port sustainability and are linked to the management of increasingly sustainable maritime ports identified in the NEXUS project (Au-Yong-Oliveira *et al.*, 2024):

- Business, Management and Accounting covers sustainable business practices and management strategies that directly influence supply chain performance (Chkoniya, 2021).
- Economics, Econometrics and Finance allows for the assessment of economic and financial impacts of sustainability in port operations, as well as performance evaluation and economic feasibility models (Cacho et al., 2021).
- Social Sciences provides essential perspectives on social impacts, governance, and public policy, which are increasingly relevant in sustainability assessments of logistics systems (International Association of Ports and Harbors, 2024).

The environmental aspect is not included in this paper, since it requires dedicated research, with a focus that goes beyond the management perspective. In the document type category, they were limited to articles and reviews. The language was limited to Portuguese and English. The type of source was limited to journals, which undergo a more rigorous and iterative review process than other types of publications (including, for example, book chapters and conference articles). Access was limited to all open access. The result compiled 36 articles.

The next step involves exporting the articles to an Excel spreadsheet. This enabled each author to identify potential studies for inclusion in the review, as well as track the selection and analysis process of the articles by reading their keywords and abstracts considering the following criteria:

- Does the abstract address the supply chain, mentioning sustainability assessment indicators or frameworks?

Articles were then equally distributed among the researchers and categorised. According to the independent analysis, all the articles were attributed colours to guide future analysis:

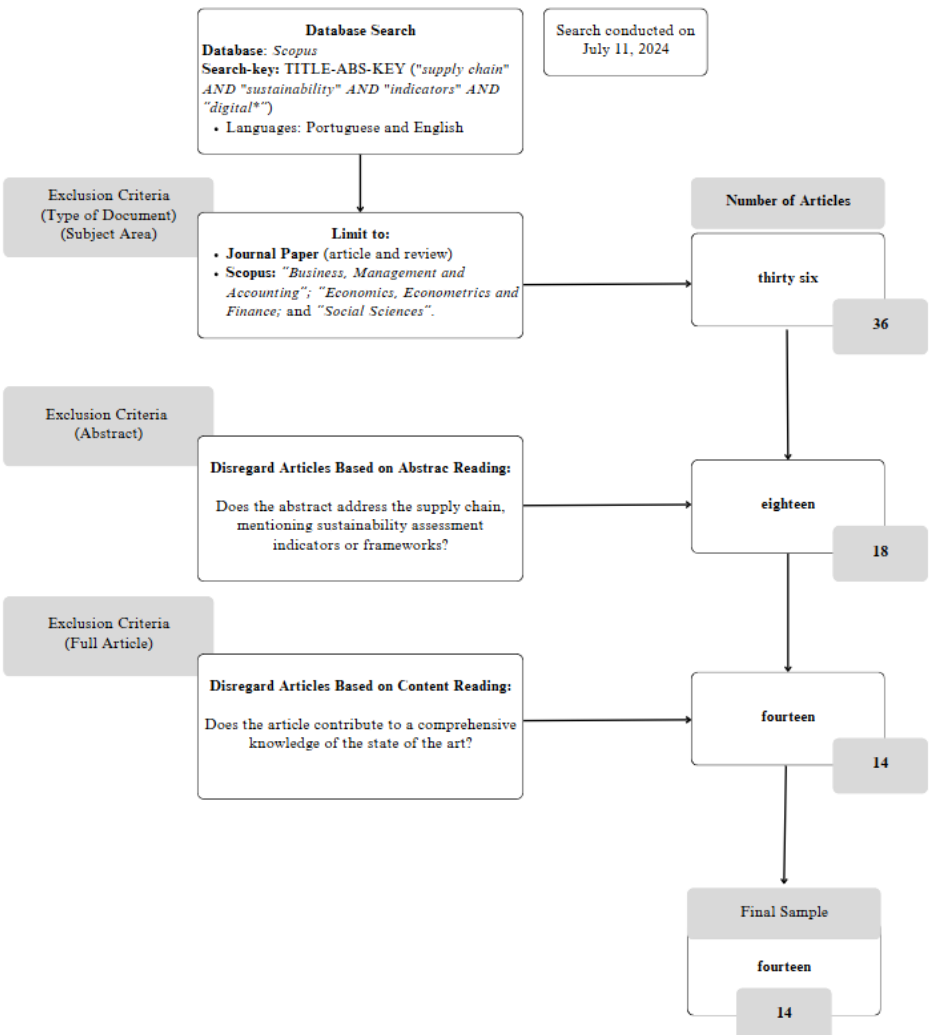
- Green: completely answered.
- Yellow: partially answered/could enrich the research.
- Red: Does not answer or contribute to the research topic.

Following this approach, 15 articles were categorized as green and selected for this study. This number was unanimously reached after joint discussion and analysis by the researchers (Xiao and Watson, 2019). One of the articles originally considered for the study was not used due to a lack of access to the full article on the date of writing. From the research, three articles were evaluated as yellow, and 18 articles were disregarded. The articles were fully read and, analysed and then selected whenever they met the following criteria:

- Does the article contribute to a comprehensive knowledge of the state of the art?

Hence, 14 articles were analysed. Figure 1 provides an overview of the selection process based on PRISMA. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) is a set of evidence-based guidelines designed to assist authors in conducting and presenting systematic reviews (Moher *et al.*, 2015). These guidelines offer specific recommendations for

Figure 1 - PRISMA-based Schema (own elaboration)



every stage of the systematic review process and involve thoroughly examining large volumes of text by several reviewers, which demands significant human effort (O'Connor *et al.*, 2014).

Table 1 shows the articles analysed in the systematic literature review. The main themes or categories identified are the following: Industry 4.0, Industry 5.0, circular economy, sustainability, competitiveness, performance (of ports / supply chain), business and territory management, digital technologies, digital transformation, and ethics, applied to different case scenarios. This preliminary analysis will be further simplified below (into four main thematic groups).

Table 1 - Articles analysed in the systematic literature review

N.	Document Title	Authors	Year	Journal
1	The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company	Garcia-Muiña F.E.; González-Sánchez R.; Ferrari A.M.; Settembre-Blundo D.	2018	*Social Sciences*
2	The effect of blockchain technology on supply chain sustainability performance	Park A.; Li H.	2021	*Sustainability (Switzerland)*
3	A Framework for Adopting a Sustainable Smart Sea Port Index	Othman A.; El-Gazzar S.; Knez M.	2022	*Sustainability (Switzerland)*
4	Developing and validating an instrument to measure the impact of digital supply chain activities on sustainable performance	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2023	*Journal of Enterprise Information Management*
5	To Align Technological Advancement and Ethical Conduct: An Analysis of the Relationship between Digital Technologies and Sustainable Decision-Making Processes	Riso T.; Morrone C.	2023	*Sustainability (Switzerland)*
6	Sustainable Supply Chain Management, Performance Measurement, and Management: A Review	Kumar A.; Shrivastav S.K.; Shrivastava A.K.; Panigrahi R.R.; Mardani A.; Cavallaro F.	2023	*Sustainability (Switzerland)*
7	Readiness and Maturity of Smart and Sustainable Supply Chains: A Model Proposal	Demir S.; Gunduz M.A.; Kayikci Y.; Paksoy T.	2023	*EMJ - Engineering Management Journal*
8	A cyclic and holistic methodology to exploit the Supply Chain Digital Twin concept towards a more resilient and sustainable future	Cimino A.; Longo F.; Mirabelli G.; Solina V.	2024	*Cleaner Logistics and Supply Chain*
9	Utilising Digital Twins to Bolster the Sustainability of Logistics Processes in Industry 4.0	Rigó L.; Fabianová J.; Lokšík M.; Mikušová N.	2024	*Sustainability (Switzerland)*

N.	Document Title	Authors	Year	Journal
10	Framework to supporting monitoring the circular economy in the context of industry 5.0: A proposal considering circularity indicators, digital transformation, and sustainability	Payer R.C.; Quelhas O.L.G.; Bergiante N.C.R.	2024	*Journal of Cleaner Production*
11	Digital transformation and corporate green supply chain efficiency: Evidence from China	Liao F.; Hu Y.; Chen M.; Xu S.	2024	*Economic Analysis and Policy*
12	Assessing sustainable supply chain transparency practices in Taiwan semiconductor industry: A hierarchical interdependence approach.	Bui T.-D.	2024	*International Journal of Production Economics*
13	Proposing a conceptual model of the sustainable digital supply chain in manufacturing companies: a qualitative approach	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2024	*Journal of Enterprise Information Management*
14	Industry 4.0 and Sustainability Integration in the Supply Chains of Micro, Small, and Medium Enterprises through People, Process, and Technology within the Triple Bottom Line Perspective	Machado E.A.; Scavarda L.F.; Caiado R.G.G.; Santos R.S.	2024	*Sustainability (Switzerland)*

The articles were analysed with the aim of identifying similar and dissimilar perspectives and restructuring the data from a different angle (Denyer and Tranfield, 2009). The key aspects of each selected article were then identified and summarized.

Finally, the articles were organized into four main thematic groups identified below, each with subtopics explained in the results section:

- Smart Port Requirements and Sustainable Performance;
- Technological Innovations Driving Sustainable Supply Chain Management;
- Circular Economy and Digital Supply Chain Sustainability;
- Frameworks and Models for Integrating Sustainable Digital Supply Chain.

Table 2 shows how the articles analysed correspond to the four main thematic areas identified.

Table 2 - Articles Analysed by Thematic Area (own elaboration)

Thematic Area	Document Title	Authors	Year
Smart Port Requirements and Sustainable Performance	Developing and validating an instrument to measure the impact of digital supply chain activities on sustainable performance	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2023
	Readiness and Maturity of Smart and Sustainable Supply Chains: A Model Proposal	Demir S.; Gunduz M.A.; Kayikci Y.; Paksoy T.	2023

Thematic Area	Document Title	Authors	Year
Technological Innovations Driving Sustainable Supply Chain Management	The effect of blockchain technology on supply chain sustainability performance	Park A.; Li H.	2021
	Sustainable Supply Chain Management, Performance Measurement, and Management: A Review	Kumar A.; Shrivastav S.K.; Shrivastava A.K.; Panigrahi R.R.; Mardani A.; Cavallaro F.	2023
	Utilising Digital Twins to Bolster the Sustainability of Logistics Processes in Industry 4.0	Rigó L.; Fabianová J.; Lokšík M.; Mikušová N.	2024
	Digital transformation and corporate green supply chain efficiency: Evidence from China	Liao F.; Hu Y.; Chen M.; Xu S.	2024
	Proposing a conceptual model of the sustainable digital supply chain in manufacturing companies: a qualitative approach	Ahmad Amouei M.; Valmohammadi C.; Fathi K.	2024
	To Align Technological Advancement and Ethical Conduct: An Analysis of the Relationship between Digital Technologies and Sustainable Decision-Making Processes	Riso T.; Morrone C.	2023
Circular Economy and Digital Supply Chain Sustainability	The paradigms of Industry 4.0 and circular economy as enabling drivers for the competitiveness of businesses and territories: The case of an Italian ceramic tiles manufacturing company	Garcia-Muiña F.E.; González-Sánchez R.; Ferrari A.M.; Settembre-Blundo D.	2018
	Framework to support monitoring the circular economy in the context of Industry 5.0: A proposal considering circularity indicators, digital transformation, and sustainability	Payer R.C.; Quelhas O.L.G.; Bergiante N.C.R.	2024
	Assessing sustainable supply chain transparency practices in the Taiwan semiconductor industry: A hierarchical interdependence approach.	Bui T.-D.	2024
Frameworks and Models for Integrating Sustainable Digital Supply Chain	A Framework for Adopting a Sustainable Smart Sea Port Index	Othman A.; El-Gazzar S.; Knez M.	2022
	A cyclic and holistic methodology to exploit the Supply Chain Digital Twin concept towards a more resilient and sustainable future	Cimino A.; Longo F.; Mirabelli G.; Solina V.	2024
	Industry 4.0 and Sustainability Integration in the Supply Chains of Micro, Small, and Medium Enterprises through People, Process, and Technology within the Triple Bottom Line Perspective	Machado E.A.; Scavarda L.F.; Caiado R.G.G.; Santos R.S.	2024

4. Results and Discussion

4.1. *Sample Characterization*

The sample analysed in this literature review includes articles published in various scientific journals, as shown in Figure 2. Most of the articles were published in the journal Sustainability (Switzerland), with six articles, followed by the Journal of Cleaner Production, which contributed three publications. The other journals, such as Business Strategy and the Environment, Energy Policy and Economic Analysis and Policy, contributed less, with one or two articles each. Concerning the year of publication, as shown in Figure 3, there is an upward trend in publications over time. Between 2018 and 2020, the number of articles published was relatively low, varying between one and two per year. However, from 2022 onwards, there was a significant increase, culminating in seven articles published in 2023 and a projection that this trend will continue in 2024. A significant increase can be observed from 2022 onwards, with a peak in 2023, indicating a growing interest in the topic in recent years. Furthermore, this recent increase suggests that the topic in question aligns with contemporary discussions, possibly reflecting the urgency of new research and solutions to emerging issues.

The business environment and the new digital transformation era are putting pressure on the global supply chain and, consequently, on ports. To cope with the new demands, ports must adapt to the new technologies and become smarter. Because of its relevance, there are several studies focusing on the requirements for smart ports.

Figure 2 - Source of Publication

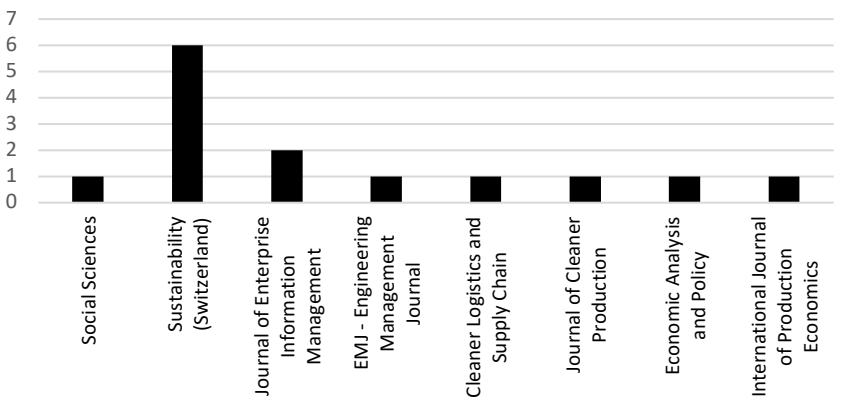
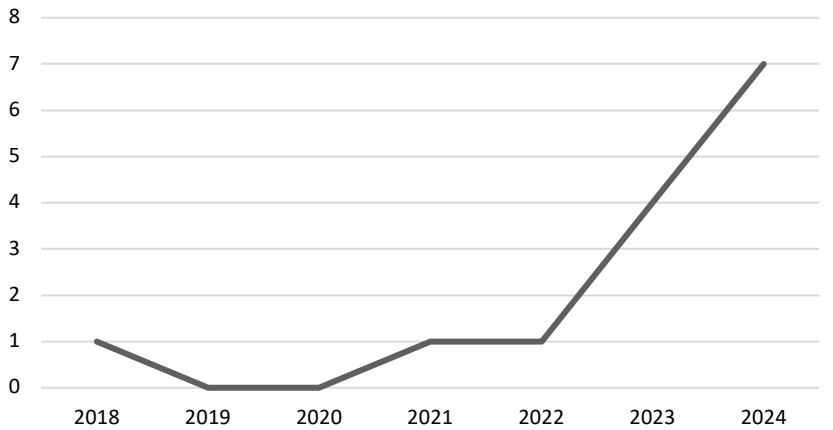


Figure 3 - Articles published during the period 2018-2024



4.2. *Smart Port Requirements and Sustainable Performance*

Although previous studies have already analysed the requirements of smart ports, there is still no integrated vision that captures the different overarching elements of a smart port and shows their impact on sustainable performance to improve the economic, social, and environmental factors of ports.

Given the significant role of the port sector in modern society and its extensive business activities, this sector is of critical importance. González *et al.* (2020) emphasise that even a slight increase in profitability within this sector can lead to substantial impacts due to the high volume of port operations. Integrating the smart concept into the port sector, leading to the emergence of the term smart port, has garnered significant attention across active ports as it supports the development and sustainability of future ports. According to Bott *et al.* (2017), a smart port is characterized by feature automation, high productivity, and eco-friendly services, including port operation structures, logistics equipment, and infrastructure. Similarly, Buiza-Camacho-Camacho *et al.* (2016) highlighted those advancements in operational efficiency, energy management, and environmental considerations that characterise a smart port. Technologies such as Artificial Intelligence, Blockchain, and the Internet of Things are key to transforming port services into more interactive and efficient offerings, aligning port development with environmental goals (Jun *et al.*, 2018).

Park and Li (2021) highlight the role of blockchain technology in enhancing the social sustainability of supply chains. Social sustainability focuses on the impacts on employees, workers, customers, and local

communities. On the one hand, Blockchain technology offers transparency and traceability by ensuring that all parties involved in the supply chain can access and verify information about the origins, handling, and movement of products. This transparency reinforces trust among all stakeholders of the supply chain. On the other hand, Blockchain facilitates compliance with social and environmental regulations by providing a clear and auditable trail of information. This ease of compliance helps companies avoid legal and reputational risks associated with non-compliance. The authors also emphasise the importance of evaluating social sustainability in the supply chain through indicators like child labour, rural poverty traps, and standards of living.

The in-depth review by Kumar *et al.* (2023) reveals several significant results and directions for future Sustainable Supply Chain Management (SSCM) research. Firstly, the research confirms a positive correlation between sustainable development and SSCM, emphasising that a collaborative approach between the various stakeholders in the supply chain, such as employees, suppliers, buyers, governments, and society, can improve sustainability objectives. The study introduces a comprehensive framework for integrating sustainability indicators into supply chains, which helps to achieve the United Nations' Sustainable Development Goals (SDGs). In addition, it presents the 'House of Sustainability' framework as a method for effectively implementing sustainability practices in all three dimensions of sustainability. The discussion revolves around different dimensions of sustainability – economic, environmental, and social – and various tools and technologies that can aid in achieving these goals.

4.3. *Technological Innovations Driving Sustainable Supply Chain Management*

Based on an analysis of previous studies, Othman *et al.* (2022) conclude that the five domains associated with smart ports (operations, environment, energy, safety and security, and human resources) are independently incorporated into ports. Consequently, the authors suggest an integrated smart port index related to sustainability performance, which can be adapted to enhance sustainable smart port performance by utilizing outcome measures, identifying weaknesses and adaptation challenges, and finding ways to overcome, manage, and improve these obstacles. Additionally, ports can use this index to evaluate their standing relative to other ports.

Demir *et al.* (2023) propose a model that offers a robust framework for assessing the readiness and maturity of supply chains in the context of smart and sustainable practices. This model is valuable in guiding organisations

through the complex transition towards more sustainable and technologically advanced supply chains. A significant strength of the proposed model is its emphasis on technological capabilities. The integration of advanced technologies such as the Internet of Things (IoT), big data analytics, and artificial intelligence (AI) is crucial for developing smart supply chains. These technologies enable real-time monitoring, predictive analytics, and enhanced decision-making, which are essential for optimizing supply chain operations and achieving sustainability goals. By incorporating these technological aspects into the readiness and maturity assessment, the model ensures that organisations are not only aware of but also prepared to leverage technological advancements for sustainable supply chain management. The model's incorporation of sustainability practices is comprehensive, covering environmental, social, and economic dimensions. This holistic approach ensures that all aspects of sustainability are considered. Environmental sustainability is addressed through measures such as carbon footprint reduction, waste management, and resource conservation. Social sustainability is evaluated by examining labour practices, community impact, and stakeholder engagement. Economic sustainability is assessed by analysing cost efficiency, financial performance, and long-term viability.

Beyond Othman *et al.* (2022), Amouei *et al.* (2023) also focus their study on sustainable performance, creating and verifying a tool through a questionnaire to assess how digital supply chain operations affect the sustainable performance of Iranian manufacturing firms. The motivation of the authors to do this study is based on evidence that digital technologies and their use in supply chain operations have significantly increased in the era of Industry 4.0, and the demand for corporate social responsibility in the sustainable manufacture of goods is also growing on a global scale. The authors identify three constructs: i) main activities, which include digital supplier, manufacturing, logistics, and customer, as well as innovation; ii) support activities, made up of digital performance and technologies and human resources; iii) sustainable performance, which includes social, environmental, and economic sustainability. The results show that the digital supply chain and its support activities have a positive and significant influence on sustainable performance. Moreover, support activities have a significant effect on the core actions of the digital supply chain. Based on the questionnaire results, Amouei *et al.* (2023) conclude that, regrettably, many of the concepts associated with this problem remain unclear and unknown to those working in the supply chain. The low level of knowledge and lack of mastery of this subject might be one of the main obstacles to adopting a digital supply chain. However, for a business to survive in today's competitive and evolving business world, it is imperative to have staff with adequate skills, competencies, and experience.

4.4. *Circular Economy and Digital Supply Chain Sustainability*

Cimino *et al.* (2024) emphasise the growing need for supply chain resilience and sustainability, especially considering recent global disruptions such as natural disasters, geopolitical tensions, and the COVID-19 pandemic. The potential of new digital technologies, particularly the Supply Chain Digital Twin (SCDT), can transform supply chain management by providing dynamic, real-time information. The authors argue that one of the main advantages of supply chain modelling through digitalisation is improved visibility and real-time monitoring capabilities. SCDT provides a dynamic and comprehensive view of the supply chain, capturing data from various sources and updating the digital model in real-time. This capability allows organisations to monitor their supply chain operations continuously, identify potential disruptions early on, and respond quickly. The results of the case study conducted by the authors indicate that implementing SCDT significantly improves situational awareness, leading to more informed decision-making and proactive risk management. Using scenario analysis and predictive analytics within the SCDT framework allows organisations to simulate various disruption scenarios and assess their potential impacts on supply chain performance.

Rigó *et al.* (2024) focus on evaluating the effectiveness and applicability of the digital twin (DT) concept in strengthening supply chain sustainability. The research presented aims to integrate digital twin technology into production logistics to meet sustainability challenges. The study provides a detailed methodology for creating and implementing a digital twin using specific technologies, including SIEMENS PLC SIMATIC S7-1200, Siemens Tecnomatix Plant Simulation, OPC UA, KEPServerEX, and TIA Portal. Key findings highlight the capacity of digital twins to offer real-time insights into production processes, which facilitates prompt responses to operational disruptions and optimises resource utilisation. By simulating various scenarios, digital twins enable the identification of inefficiencies and opportunities for improvement, thereby contributing to sustainability goals such as resource conservation and reduction of environmental impact. However, the study also acknowledges certain limitations. The primary focus on specific technologies may restrict the generalizability of the findings to other contexts where different systems are employed. Additionally, the empirical examination was conducted on a hypothetical production line, which might not fully represent the complexities of real-world manufacturing environments.

Some of the publications in the sample focus on digitalisation and sustainability, such as the ones by Garcia-Muiña *et al.* (2018), Riso and Morrone (2023), Payer *et al.* (2024), Liao *et al.* (2024) and Amouei *et al.* (2024).

Garcia-Muiña *et al.* (2018) analyze the transition from a linear to a circular economy, proposing a procedure for introducing the principles of sustainability (environmental, economic, and social) into a manufacturing environment in Italy. According to the authors, sustainable development and the circular economy are key company competitiveness issues. To achieve satisfactory levels of sustainability, production processes need to be reconfigured to develop eco-sustainable products. This requires the participation and commitment of different stakeholder groups, so the industry must redesign supply chains with a view toward resource efficiency and circularity. Adopting a circular economy implies the need to review the implementation of the entire supply chain contained in each cycle of production (Tantau *et al.*, 2018). The evolution of technology, such as the Internet of Things, contributes to this systemic transition.

Riso and Morrone (2023) conducted a structured literature review focusing on the relationship between digitalization and sustainability and on publications between 2019 and 2023. Some of the papers analyzed focus on green supply chains and logistics. However, a few studies explore how business strategy professionals might use sustainable decision-making processes to help develop sustainable goals. Some of the studies they examine pay attention to the theme of green supply chain, logistics, and digital management. This trend has been developed in recent years by resilience and agility in supply chains due to digital technologies, particularly during the COVID-19 pandemic (Riso and Morrone, 2023). Supply chain 4.0, a transformational strategic development, effectively triggers resilience, playing a crucial role in facing COVID-19 (Frederico, 2021). According to Dwivedi and Paul (2022), eliminating barriers to digital supply chain progress is crucial for transforming traditional supply chains into sustainable digital ones. Moreover, the authors argue that the modification of supply chains is a determinant of adopting circular economy values. However, supply chain finance is a challenge, needing the adoption of finance and supply-chain perspectives and connecting several stakeholders, such as buyers, sellers, and banks, to create a sustainable supply chain for firms' success (Alsmadi *et al.*, 2022). Based on the literature review, Riso and Morrone (2023) suggest some topics for future research, such as the examination of crucial circular supply chain management and associated metrics, with the aim of illuminating the optimal functioning in sustainable circular supply networks that may be discerned through measures (Saraji and Streimikiene, 2022) and examine how the digital revolution affects sustainable supply chains and how cooperation between various actors is essential to the success of sustainable supply chain management (Tseng *et al.*, 2019).

Payer *et al.* (2024) elaborate a framework to address the topics of digital transformation, the Industry 5.0 paradigm, and the Environment, Social, and

Governance (ESG) components of sustainability that will help companies adopt a circular economy. The authors find seven dimensions that must be considered to hit the circularity, one of them being the circular and non-circular supply chain integration. Regarding the supply chain, the authors highlight the necessity to include circularity and sustainability (mainly the social and environmental pillars) topics and to have real-time information. In the same vein, Varriale *et al.* (2023) also emphasise the relevance of these topics to increase supply chain transparency, as stakeholders become more aware of the manufacturing processes of goods, and industries can be aware of the more efficient resources and cut costs and waste to enhance the circular practices. The integration of supply chains requires principles of Industry 5.0 (Camarinha-Matos *et al.*, 2024) and optimisation, which can be achieved through new technologies, such as digital transformation (Payer *et al.*, 2024). Although there are several advantages of digital transformation for the integration of circular and non-circular supply chains, some authors draw attention to various challenges, such as the need to apply digital transformation throughout the chain (Karmaker *et al.*, 2023), enabling them to obtain interconnected smart and decentralized chains (Belhadi *et al.*, 2021). On the other hand, it is necessary to obtain, develop, and use appropriate information and knowledge to implement the desired changes in business operations (Ghobakhloo *et al.*, 2023) to be efficient.

In the context of the growing use of digital technology by businesses to promote sustainability in the age of the digital economy, and when it is crucial to optimize the green supply chain, Liao *et al.* (2024) analyze data from Chinese manufacturing companies registered on the A-share market, for the period from 2011 to 2020. The authors explore their relationship by extracting digital transformation indicators and evaluating the effectiveness of eco-friendly supply chains. The results demonstrate that digital transformation enhances green supply chains' overall efficiency by fostering innovation in green technologies, lowering transaction costs, and easing finance limitations. The positive impact of digital transformation on green supply chains is in line with previous studies, such as the ones by Agyabeng-Mensah *et al.* (2023), Qin *et al.* (2023), and Su *et al.* (2023). Furthermore, the evidence shows that government-owned businesses, big firms, and those with lower per-capita production values are especially affected by digital transformation's ability to increase efficiency in green supply chains.

4.5. *Frameworks and Models for Integrating Sustainable Digital Supply Chain*

Bui (2024) identifies valid attributes of sustainable supply chain transparency, examining causal relationships, assessing hierarchical

interdependencies, and indicating priority practices in the context of Taiwan's semiconductor industry, contributing to detecting sustainable supply chain transparency structures, particularly when transparency extends beyond the actual operation of the supply chain, which involves various uncertain and complex factors. Sustainable supply chain transparency is established to improve the disclosure and visibility of sustainability information inside and outside the supply chain. The findings suggest that efforts of transparency made by stakeholders, digital expertise, and information management are causal characteristics that must be highlighted to enhance sustainable supply chain transparency. In addition, the author argues that digital competencies significantly enhance sustainable supply chain transparency by leveraging technologies such as Blockchain, the Internet of Things, and Artificial Intelligence, which agrees with previous arguments (Jun *et al*., 2018; Karmaker *et al*., 2023; Riso and Morrone, 2023).

Amouei *et al*. (2024), after creating a tool to analyze the impact of digital supply chain operations on sustainable performance (Amouei *et al*., 2023), now propose a conceptual model for a sustainable digital supply chain management in manufacturing companies, given the significance of the sustainable supply chain management and the industry 4.0 in supply chain management. According to the authors, emerging technologies have impacted every industry in the digital age. Digital, information, and communications technologies have made traditional supply chains more innovative and more resilient, allowing for better handling of risks. To carry out the study, Amouei *et al*. (2024) performed a literature review of many publications and ran some interviews with manufacturing specialists. Considering the suggested model, the digital supply chain management is composed of four sections: i) the digital supplier, which includes the "supplier evaluation and selection", "supplier segmentation", "duration of the relationship with the supplier", and "quality of relationship with the supplier"; ii) digital manufacturing, that incorporates the "supply chain transparency", the "digital customization", the "digital processes" and the "digital strategies"; iii) digital logistics and innovation, including the subjects of "digital logistics", "digital business model", "digital research and development" and "open innovation"; iv) digital customer, which comprises the issues of "customer relations", "digital delivery service", "customer feedback", "customer experience" and "customer training". Based on the study's findings, the authors conclude that support actions impact the primary activities of the digital supply chain. Digital performance, for instance, can lessen any current supply and demand mismatch and boost transparency throughout the supply chain, which eventually improves the company's competitive edge. The performance of the primary operations will be enhanced using digital technology through process integration, increased information availability, real-time inventory

monitoring, customer interaction, and cost savings. Finally, by utilizing cutting-edge technology in recruiting, training, and developing staff members, digital human resources can impact digital innovation and other key tasks. These conclusions are in accordance with previous studies (e.g., Agrawal and Narain, 2018).

Considering the suggested conceptual model, the consequences of digital technology use on supply chain management sustainability, and their findings, Amouei *et al.* (2024, p. 562-563) suggest three propositions: P1) "The use of digital technologies in supply chain support activities has a positive and significant effect on the supply chain main activities"; P2) "The use of digital technologies in supply chain main activities has a positive and significant effect on supply chain management sustainability"; P3) "The use of digital technologies in supply chain support activities has a positive and significant effect on supply chain management sustainability".

Machado *et al.* (2024) propose a framework to support the integration of Industry 4.0 and sustainability into supply chains, focusing on micro, small, and medium-sized enterprises. Based on a literature review, focus groups, and a survey of experts, the authors identified 32 key indicators associated with the main barriers and the main facilitators of Industry 4.0 and sustainability integration in these companies' supply chains. Some of the barriers are the lack of technical expertise, cybersecurity issues, resistance to change management practices, and adoption of innovation, and some of the factors are the internal innovation process, data-centred solutions, consistent data flow, and customer and supplier integration. Some barriers can be mitigated by facilitators, which is very important that firms are aware of. The results were also synthesized into a new framework, applied separately to Micro and Small Enterprises (MSEs) and Medium Enterprises (MEs) due to the companies' size differences, concluding that there is a need to treat MSEs and MEs differently when it comes to integrating Industry 4.0 and sustainability into their supply chains, allowing this process to be accelerated. MSE managers, for example, ought to concentrate on obstacles since they have a greater impact than MEs. However, in their quest for a bigger business impact, MEs managers must pay more attention to facilitators. For example, the barrier of the cost of improvement and economic state of operations and supply chain management is more relevant and influential to MSEs than it is to MEs. The facilitator related to top management commitment and strategic alignment must be paid attention to both in MSEs and MEs contexts. The authors conclude that if sustainability has gained importance in the case of Industry 4.0 implementation in MSME (Micro, Small & Medium Enterprises) supply chains, this may have an even greater effect on Industry 5.0 or Society 5.0 visions.

The model proposed by Lahane *et al.* (2023) to evaluate and rank solutions for overcoming barriers to adopting Industry 4.0 technologies in sustainable

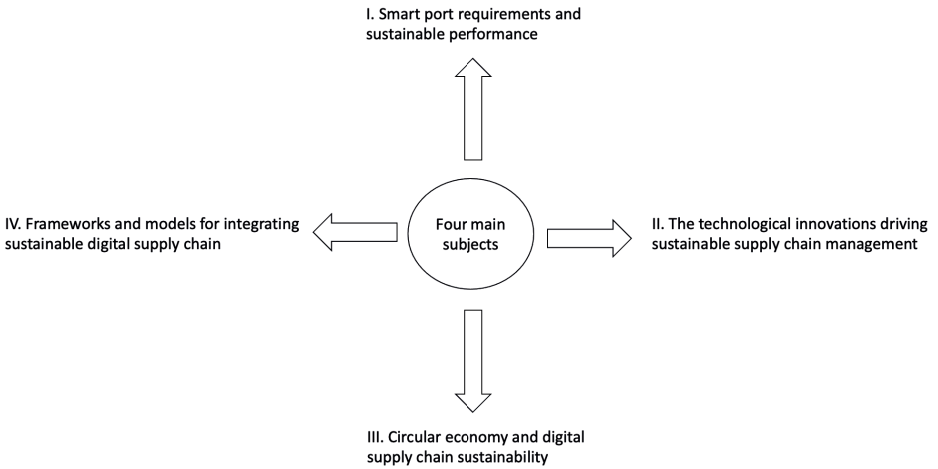
food supply chains is a comprehensive framework that addresses the multifaceted nature of this challenge. By employing multi-criteria decision-making methods (MCDM), the model provides a structured approach to decision-making that incorporates a wide range of factors relevant to sustainability and technological adoption. The identification of barriers is a critical first step in the model. The categorisation into technological, economic, organisational, regulatory, and social domains ensures that all potential obstacles are considered. This holistic approach is essential because the successful implementation of Industry 4.0 technologies in the supply chain is contingent on addressing challenges across these diverse areas. The application of MCDM methods such as the Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), and Decision-Making Trial and Evaluation Laboratory (DEMATEL) is a significant strength of the model. These methods facilitate a rigorous and systematic evaluation of solutions, allowing for nuanced decision-making. AHP, for instance, enables the decomposition of complex decisions into simpler, more manageable components, facilitating a thorough analysis of each criterion. TOPSIS, on the other hand, helps identify solutions closest to the ideal and farthest from the negative ideal, providing a clear preference order. DEMATEL visualises the structure of complex causal relationships, aiding in identifying key factors and their interrelationships.

The model proposed by Lahane *et al.* (2023) offers a rigorous and comprehensive approach to evaluating and overcoming barriers to adopting Industry 4.0 technologies in sustainable food supply chains. By integrating MCDM methods with a holistic consideration of barriers and solutions, the model provides a valuable tool for stakeholders seeking to enhance the sustainability of their supply chains.

4.6. *Discussion*

Based on the results of the 14 publications, the main subjects that researchers focused on were identified: i) smart port requirements and sustainable performance (e.g., González *et al.*, 2020; Park and Li, 2021; Othman *et al.*, 2022); ii) the technological innovations driving sustainable supply chain management (Othman *et al.,* 2022; Amouei *et al.*, 2023; Demir *et al.*, 2023); iii) circular economy and digital supply chain sustainability, such as the studies by Garcia-Muiña *et al.* (2018), Riso and Morrone (2023), Payer *et al.* (2024), Liao *et al.* (2024) and Amouei *et al.* (2024) and; iv) frameworks and models for integrating sustainable digital supply chain (Amouei *et al.*, 2023, 2024; Machado *et al.*, 2024) (Figure 4).

Figure 4 - The four main subjects highlighted by literature

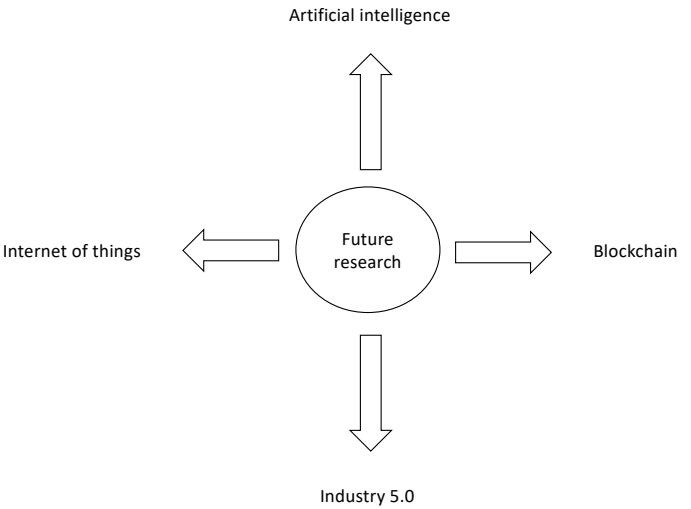


Note the presence of elements such as sustainable performance (no other type of performance should matter), technological innovations (innovation is indissociable from technology), digital supply chain (a natural evolution free of human intervention), and frameworks and models (for theorists to pursue further their applied research).

Several gaps identified in this work present opportunities for future research (see Figure 5). As Industry 5.0 gains traction, it is increasingly important to assess the additional value it offers beyond the capabilities of Industry 4.0, particularly in fostering human-centric, resilient, and sustainable systems. Moreover, there is a need to analyse the impact of advanced technologies, such as Artificial Intelligence, Blockchain, and the Internet of Things, on port operations, with a particular focus on their contributions to efficiency improvements and the achievement of environmental objectives.

Finally, it is essential to place greater emphasis on social sustainability in the supply chain, particularly through the development and application of indicators that evaluate critical social issues such as child labour, rural poverty traps, standards of living, and the role of the food economy in promoting equitable development. Tackling these dimensions is crucial to building more inclusive, intelligent, and sustainable port and supply chain systems, aligned with the broader objectives of Industry 5.0 and global sustainability agendas.

Figure 5 - The gaps identified in this study



5. Conclusion, Limitations and Future Research

This study analyses the research trends in sustainable supply chains in the Scopus database, which was researched on July 11, 2024. Considering the sample selection process, 14 documents were obtained. To the best of the authors' knowledge, few studies have addressed this subject. The most influential works were identified, and an integrated analysis was performed. The increase in publications after 2022 reflects the recognition of the benefits of sustainable practices and digitalisation to improve supply chain efficiency. The relevance of sustainable practices is reinforced by the evidence that a major part of the papers was published in the Sustainability journal.

This study is important for managers because it identifies practices that can improve supply chain management, and it is important to realise that the staff need adequate skills, competencies, and experience. Moreover, this study shows some findings that can lead researchers to new avenues for further research on this subject.

The limitation is that it considers only the Scopus database, which can bias the sampling method. Thus, in the future, it would be valuable to use another bibliometric source, such as the Web of Science (WoS) database.

Future research could cover the gaps identified in this work (Figure 5), such as analyzing the effects of Technologies like Artificial Intelligence, Blockchain, and the Internet of Things on the efficiency and environmental goals of ports, evaluating social sustainability in the supply chain through

indicators like child labor, rural poverty traps, and standards of living. Other research opportunities can focus on the examination of crucial circular supply chain management and associated metrics to illuminate the optimal functioning in sustainable circular supply networks, as well as to examine how the digital revolution affects sustainable supply chains and how cooperation between various actors is essential to the success of sustainable supply chain management.

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Assessing Agricultural Resilience in Malaysia: The Impact of R&D Investments on Sector Stability

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Abstract

The agricultural sector is pivotal in Malaysia's economic development, primarily providing food, feed, and raw materials for industries while contributing to the country's GDP and absorbing labour. Despite its significance, the sector's resilience during economic shocks, such as financial crises, economic setbacks, and pandemics, requires further examination. This study addresses the issue of measuring the resilience of Malaysia's agricultural sector with an enhanced focus on the impact of research and development (R&D) funding allocation and investments, which is often overlooked in resilience studies. It aims to quantify the resilience of Malaysia's agricultural sector and analyse trends over time, thereby contributing to a deeper understanding of the sector's stability and the role of R&D in fostering resilience. Secondary data from 1996 to 2023 was collected from various sources, including the World Bank, the Department of Statistics Malaysia, the Ministry of Agriculture and Food Industries Malaysia, Bank Negara Malaysia, and the Malaysian Investment Development Authority. Principal component analysis (PCA) was utilised to construct the resilience index, while trend analysis examined the evolution of this index over the study period. Preliminary

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results indicate that the resilience of Malaysia's agricultural sector fluctuates over time, with a positive correlation between increased R&D investments and higher resilience levels. The findings suggest that strategic R&D investments are crucial for enhancing agricultural resilience. By integrating R&D factors, this research provides a comprehensive framework for assessing the resilience of the agricultural sector, offering policymakers and stakeholders valuable insights. The methodology and findings can also be applied to other countries, making a significant contribution to the literature on agricultural resilience.

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Introduction

The agricultural sector is not only a mainstay of economic development and poverty reduction (World Bank, 2020) but also plays a vital role in maintaining food security and safety in most developing countries (Diao *et al.*, 2007). However, the agricultural sector in Malaysia faces various challenges, including climate change (Firdaus *et al.*, 2020), economic uncertainty (Yang *et al.*, 2022; Hamidu *et al.*, 2022), and a shortage of skilled labour (Cassey *et al.*, 2018). These challenges affect the resilience of agricultural production and require urgent adaptation, enabling the agricultural sector to remain productive despite disruptions from climate change, economic uncertainty, and labour shortages.

In addition, several agricultural sectors, such as rice, are highly vulnerable to external shocks that affect exports. Both sectors face pressure from fluctuating commodity prices in global markets, currency depreciation and trade policies from trading partner countries (Hamidu *et al.*, 2022). This, in turn, affects the income of smallholders and limits investment in modern agricultural techniques. Therefore, the oil palm and rubber sectors always need financial assistance to help diversify other agricultural products to overcome these challenges.

In addition, there is also a labour shortage (Prasad, 2017; Tittonell, 2020), and most young people are more likely to migrate to rural areas to work in other sectors. They are less interested in jobs in the agricultural sector. This has led the agricultural sector to rely more heavily on foreign labour in the plantation sector, raising concerns about long-term sustainability, particularly with the increasingly strict recruitment of foreign labour and the rising minimum wage for foreign labour. Meanwhile, the younger generation is more interested in finding more modern job opportunities than traditional agricultural jobs. This has led to a constant shortage of labour

in the agricultural sector. Modernisation can overcome this challenge in the agricultural sector through government initiatives from the Technical Vocational Education and Training (TVET) program to attract young people to modern agriculture. This approach ensures that labour in the agricultural sector is always sufficient, allowing the sector to remain competitive and resilient. Agricultural resilience refers to the ability of the agricultural sector to remain productive and adapt and recover from the effects of disruptions. These include climate change disruptions (Firdaus *et al*., 2020), changes in commodity prices (Cassey *et al*., 2018) and labour shortages (Tittonell, 2020; Meuwissen *et al*., 2019). Agricultural resilience is crucial for ensuring food security (Tendall *et al*., 2015; FAO, 2020) and maintaining the stability of the food chain (Hamidu *et al*., 2022).

Among the practices to increase agricultural resilience are climate-smart practices such as conserving cropland, maintaining sound drainage systems, and agroforestry (Tittonell, 2020; FAO, 2020). These are examples of competitive agricultural practice systems. They aim to ensure that the agricultural sector remains productive despite extreme weather changes, and are a step towards modernising agricultural technologies such as automated irrigation and remote sensing techniques.

Second is economic resilience, in other words, the financial resilience of farmers during economic uncertainty and climate change without affecting the productivity of the agricultural sector. Financial assistance includes encouraging crop diversification, using innovative technology, and using machinery. This secures the entire food supply chain. Financial support and R&D investment are needed to ensure economic resilience (Fuglie, 2018).

Third, agricultural resilience in terms of the social and institutional roles that support food security in the face of economic uncertainty, climate change and labour shortages. There is a network of government or community agencies that can provide training and technical assistance support to farmers (Meuwissen *et al*., 2019), such as the use of digital marketing platforms that enable wider marketing of agricultural products and the use of cold storage technology to ensure that agricultural products remain fresh and last longer. In addition, the use of sophisticated machinery can overcome labour shortages.

Therefore, investment in R&D is essential to maintain food security by ensuring continued productivity despite current challenges, and several other countries have implemented similar measures. For example, in Africa, climate-smart agriculture (CSA) is used to overcome rainfall problems and, at the same time, promote drought-resistant crops and agroforestry (Adger *et al*., 2020; Lipper *et al*., 2020). Meanwhile, Brazil is practising crop diversification (Altieri & Nicholls, 2020), and farmers from the European Union and the United States are adopting drone support systems and artificial intelligence

in agriculture to help farmers make the right decisions (Fuglie, 2018). The Netherlands uses hydroponics to overcome land scarcity and unpredictable weather conditions (Fuglie, 2018). Vietnam, Indonesia and the Philippines are relevant in using flood-resistant rice seeds to enhance food resilience (Rumanti *et al*., 2018). China promotes solar-powered irrigation programs, organic farming and crop insurance (Pingali, 2019).

The Malaysian agricultural sector faces various challenges that can affect productivity and sustainability in the long term. Among them are climate change, extreme weather, and drought affecting agricultural production (Firdaus *et al*., 2020), mainly due to deforestation and land degradation activities that affect the sustainability of oil palm and rubber areas (FAO, 2020). In addition, economic and global market uncertainties affect global agricultural product demand (Cassey *et al*., 2018) and increase fertiliser costs, significantly impacting the resilience of smallholder farmers (World Bank, 2020). At the same time, the agricultural sector is experiencing a shortage of workers due to over-reliance on foreign workers. In addition, foreign worker recruitment policies are becoming stricter to reduce the recruitment of illegal foreign workers (Low, 2017) and local workers are less interested in the agricultural sector (Abdullah *et al*., 2016). The challenge of agriculture to remain resilient occurs with technological constraints and facilities that smallholder farmers face, such as limited access to modern agricultural technology and digital equipment (Zahari *et al*., 2024). Capital constraints to use technology cause inefficiencies in the food supply chain, such as a lack of storage facilities and transportation networks.

The Function of R&D in Enhancing Agricultural Resilience

Malaysia has adopted several policies to support innovation and improve agricultural resilience. However, a gap exists between the implementation of agricultural resilience policies and the actual situation (Hassan *et al*., 2022). This is due to the constraints of limited financial support and insufficient investment in R&D to develop sustainable agricultural systems (Zahari *et al*., 2024; Fuglie, 2018). Therefore, various aspects should be considered, such as strategies for climate change adaptation, economic policy reforms, workforce development and technological innovation to strengthen agricultural resilience and ensure food security in the long term. In other words, findings from R&D can also help policymakers and farmers restore agricultural productivity to overcome the challenges of climate change, global market volatility and shortages of raw material resources (Fuglie, 2018).

R&D also drives the creation of better breeds and provides better agricultural yields (Thornton *et al*., 2021). In addition to the use of smart

agriculture, including the use of remote sensing applications, artificial intelligence (AI) and the Internet of Things (IoT) so that agricultural activities can be monitored remotely and more accurate decisions can be made by optimising the use of fertilisers, water and soil (Alston *et al*., 2011). R&D provides empirically based insights to policymakers to improve food security. For example, modernising agricultural systems can reduce dependence on foreign labour, increase overall competitiveness, and ensure that agricultural systems can cope with future economic uncertainties.

R&D can potentially improve agriculture's long-term sustainability (Chandio *et al*., 2025). However, financial constraints still exist, especially with investments in modern technologies, such as innovative harvesting equipment, weather-resistant crop genetics, and efficient irrigation systems. In addition, the lack of investment from the private sector in R&D has led to the slow development of agricultural technology (Fuglie, 2018). In addition, government initiatives such as the Young Agroprenuer Grant promote modern agriculture, but bureaucratic inefficiency still restricts accessibility and effectiveness (Hassan *et al*., 2022). Meanwhile, banking institutions often see agriculture as risky, causing them to hesitate to lend to small farmers. In addition, the lack of technical knowledge and training for farmers is the main reason they do not practice and find it difficult to accept modern agricultural systems. Agricultural training and skills programs in Malaysia seem inadequate, and there is still a lack of research collaboration networks between universities and agricultural research institutions such as the Malaysian Agricultural Research and Development Institute (MARDI). Weak collaboration between researchers and agricultural practitioners hinders the development of new agricultural technologies and reduces agricultural sustainability.

Most agricultural areas in Malaysia are developed in rural and remote areas, with poor infrastructure, inadequate irrigation systems, and lack of electricity and internet coverage. This hinders farmers' ability to adopt modern farming systems (FAO, 2020), while limited internet coverage restricts farmers' access to weather forecasting applications, digital marketing, and remote sensing technologies (Lipper *et al*., 2020).

However, several past researches have proposed various strategies for the agricultural sector. It is to become a resilient sector, such as strategies to increase productivity capacity (see Alston *et al*., 2011; Pardey *et al*., 2021; Fuglie, 2018). However, research gaps still exist, especially in assessing the extent to which resilience occurs in the agricultural sector and the role of R&D investment in the agricultural sector. It aims to strengthen resilience to face global economic uncertainties and climate change by developing the Agricultural Resilience Index (ARI) by combining social, economic and

environmental indicators using Principal Component Analysis (PCA) and trend analysis from 1996 to 2023.

1. Literature Review

Related Theories

The current complex macroeconomic situation dramatically affects the agricultural environment, which various related theories can explain in terms of resilience in agriculture. It is important to understand how the agricultural sector can adapt when facing the uncertainty of economic pressure, labour market, economic resource market, government intervention, and the role of agricultural innovation to ensure the survival of the rapidly growing agricultural sector.

The theoretical relationship starts from the Business Cycle Theory, which explains fluctuating economic conditions and shows the economic phase expanding or contracting from time to time (Lucas, 1980). In the agricultural sector, the investment surge phase is the main impetus for agricultural productivity, and agricultural production is more capital-incentive to recovering the economy from the recession phase. On the other hand, monetary policy pressure slows down the expansion phase of the agricultural sector and affects the rate of labour participation in agriculture.

After the emergence of the Business Cycle Theory, the Resilience Theory became popular among researchers, economists, and policymakers in the late 20th century. It explores the response of an economy to shocks and readjusts after the effects of external disturbances (Hallegatte, 2014; Chavas, 2024). The theory explains the mechanism of stress absorption and adaptation to various uncertain economic economies. This study focuses on the resilience theory in the agriculture sector, which is important in facing various economic challenges such as global market uncertainty, extreme weather changes, and global economic policies. Economists have highlighted various strategies to ensure that the agricultural sector can enter the recovery phase and grow to be more productive despite the global economic slowdown like crop diversification (Vernooy, 2022), government support (Barbosa, 2024), and approaches for using innovation to increase the level of sustainability of the agricultural sector to adapt to various uncertain economic conditions (Cruz, 2023).

In the context of productivity, the Human Capital Theory emphasises the importance of investing in human capital through skills training and education to drive agricultural economic growth and increase the efficiency of agricultural productivity (Huffman & Orazem, 2007; Timmer, 2002;

Hoang-Khac, Tiet, To-The & Nguyen-Anh, 2022). It emphasises the productivity and efficiency of adopting up-to-date agricultural techniques and using the latest technology to ensure sustainable agricultural practices. Then came the Innovation Theory that supports agricultural resilience by highlighting technological advances as the mainstay to ensure that economic growth always occurs in the context of modern agricultural productivity, mainly research and development (R&D), biotechnology, digitalisation, and the use of artificial intelligence (AI) in agriculture. This increases productivity efficiency, reduces input costs, fosters resilience, and becomes more competitive to face economic uncertainty.

The Wage Efficiency Theory further reinforces the Resilience Theory. It was first developed by Akerlof & Yellen (1986) to explain why employers prefer to offer higher wages rather than the market equilibrium to attract more highly skilled workers with the best motivation. Real wages also play an important role in productivity (Nikoloski, 2023). A positive two-way relationship exists between labour productivity and real wages, giving an advantage to technological change (Cruz, 2023). The theory suggests that higher wage levels can increase labour productivity by using machinery and artificially intelligent technology that requires high skills from skilled and professional labour. However, these studies may not mention wage efficiency in agriculture. High wages can also attract professional and skilled labour to work in agriculture. This may overcome the labour shortage issue in the agricultural sector by using high-tech machinery that requires minimal skilled labour but can produce higher productivity than unskilled labour, especially to overcome the use of unskilled foreign labour.

The Resource-Based View (RBV) theory also supports the Resilience Theory by focusing on efficiently managing economic resources such as land use, technology, and human capital. It highlights the role of efficient economic resources and innovative agriculture practices in increasing the use of sophisticated technological machinery that requires skilled labour to operate the machinery in addition to soil that is always fertile due to more efficient fertilisation techniques. This ensures the economic sustainability of agriculture in the long term. The RBV theory, initially proposed by Wernerfelt (1984), focuses on the efficiency of firms when using internal resources but not producing products. This approach was later applied to the agricultural sector to understand competitive advantage (Madhani, 2009). Subsequently, the theory was used to study the sustainability of competitive advantage in agricultural commodities (Michaels & Gow, 2008). However, RBV may still not consider market uncertainty, which requires alternative strategic approaches (Furr & Eisenhardt, 2021).

To complete the theoretical framework of agricultural sustainability, the Market Failure Theory explains how the market fails to allocate resources

efficiently in agriculture, such as public goods. Additionally, imperfect information requires government intervention to ensure that the agricultural market ecosystem is more sustainable regarding subsidy allocation, innovation investment from the government, and government support for R&D, enabling agriculture to be conducted modernly.

Factors Affecting Agricultural Resilience

Numerous factors influence agricultural resilience, including economic policies, technological innovation, market conditions, and environmental variability. Recent literature emphasises the importance of integrating these factors into resilience assessments to capture the complex dynamics (Folke *et al*., 2016; Tendall *et al*., 2015). Economic policies like subsidies, trade agreements, and financial support can significantly impact resilience by stabilising incomes and promoting investment or creating dependencies that may undermine long-term sustainability (Jayne *et al*., 2018). Recent studies by Slijper *et al.* (2022) show that beyond economics, social capital and learning networks are vital drivers of resilience, especially in enabling farmers to adapt through shared knowledge and innovation.

R&D is critical in strengthening resilience through sustainable practices (Vermeulen *et al*., 2018), integrating climate-smart technologies and practices (Fischer *et al*., 2017), and resource efficiency by advancing technological innovation. It facilitates farmers in using agricultural tools that can help them estimate accurate resource use (Fuglie, 2018; Lipper *et al*., 2020) and reduce waste of resources, such as water, energy, and nutrients, based on analytical data generated using drones and IoT sensors. For instance, AI and remote sensing now allow real-time crop health and resource efficiency monitoring, offering transformative potential in predictive farm management (Jung *et al*., 2021). These technologies enhance the precision and scalability of resilience-building practices in agriculture. Therefore, R&D in agriculture can ensure food security by increasing resilience to global climate change shocks, thus serving as an investment opportunity in Malaysia's innovative agricultural technology.

The Malaysian agricultural sector has undergone significant transformation driven by modernisation, technological adoption, and policy reforms. However, the sector still faces challenges related to climate change (Firdaus *et al*., 2020), labour shortages (Prasad, 2017; Tittonell, 2020), and market fluctuations (Cassey *et al*., 2018). Recent studies on Malaysia's agriculture have highlighted the importance of resilience in ensuring food security and economic stability. For example, Lim *et al.* (2021) examined the impact of climate change on rice production in Malaysia, emphasising the need for

adaptive strategies to enhance resilience. Another study by Hassan *et al.* (2022) explored the role of government policies in supporting agricultural resilience, focusing on the effectiveness of subsidies and infrastructure development. Malaysian rice production faces extreme weather, poor soil fertility, farmers' lack of awareness, and limited technological deployment (Dorairaj & Govender, 2023).

In China, Gao *et al.* (2024) found that digital inclusive finance significantly enhances agricultural resilience by improving rural industrial integration and financial access. Meanwhile, Luo *et al.* (2024) demonstrated through a spatial-temporal analysis that regional disparities, urbanisation, and spatial spillovers shape resilience outcomes, which suggests the need for spatially targeted policy interventions. These studies underscore that agricultural resilience is not static but evolves in response to geographic, institutional, and technological shifts. Additionally, Boahen *et al.* (2023) revealed that resilience research varies by region, suggesting that design strategies and objectives for agricultural systems should differ by region. For instance, Nguyen *et al.* (2019) proved that agricultural systems in Vietnam's Mekong and Red River deltas need improved resilience to adapt to increased salinity intrusion and social-ecological changes.

Despite these efforts, a comprehensive, multidimensional assessment of agricultural resilience in Malaysia, particularly about R&D investments, remains limited. This study addresses the gap by developing an Agricultural Resilience Index (ARI) and analysing trends over time using advanced statistical methods such as PCA and trend analysis. This study contributes new empirical evidence and a robust framework for enhancing Malaysia's agricultural resilience by integrating technological factors, labour, policy, and financial dimensions.

Methodologies for Assessing Resilience

The methodologies for assessing agricultural resilience have evolved significantly, with a growing emphasis on quantitative approaches that allow for integrating multiple indicators (Creswell & Creswell, 2018). Principal Component Analysis (PCA) and trend analysis are standard methods used in recent resilience studies. PCA has been widely employed to construct composite indices that capture the multidimensional nature of resilience (Jolliffe & Cadima, 2016). For instance, recent studies in Indonesia and South Africa have used PCA to develop resilience indices, highlighting the most significant factors contributing to agricultural stability (Siregar *et al.*, 2024; Bahta & Myeki, 2021).

PCA is widely regarded among researchers for its effectiveness in reducing multiple indicators into a single, interpretable index. This method is particularly advantageous for capturing the multidimensional nature of agricultural resilience as it simplifies complex datasets without significant information loss (Jolliffe, 2002; Abson *et al*., 2012). Compared to time-series models such as ARIMA or multivariate analysis, PCA handles correlated variables and constructs composite indices representing overall sector stability (Filmer & Pritchett, 2001).

On the other hand, trend analysis provides insights into how long-term climate change and short-term weather disturbances affect resilience based on experience to shape future resilience strategies (He *et al*., 2024). The combination of PCA and trend analysis is particularly effective in assessing resilience as it allows for a comprehensive evaluation of the current state and the historical evolution of resilience (Yang *et al*., 2019).

2. Methodology

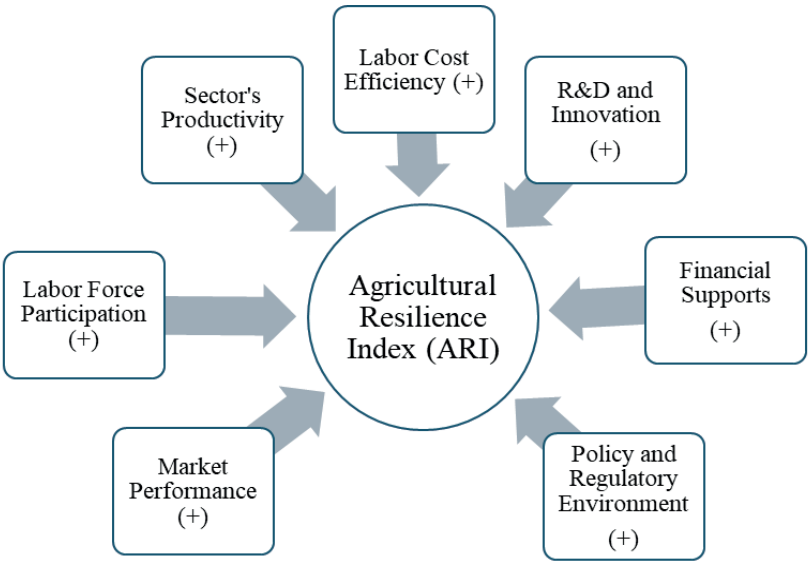
Research Design

This study employed a quantitative research design to evaluate the resilience of Malaysia's agricultural sector. Specifically, the Agricultural Resilience Index (ARI) was developed to capture multidimensional aspects of resilience. The analysis was based on secondary annual data from 1996 to 2023 from reputable sources, including the World Bank, the Department of Statistics Malaysia, the Ministry of Agriculture and Food Industries, Bank Negara Malaysia, and the Malaysian Investment Development Authority. Principal Component Analysis (PCA) was utilised to construct the ARI, as it is particularly well-suited for reducing the dimensionality of complex datasets, identifying latent patterns, and transforming multiple correlated indicators into a single composite index with minimal information loss. In addition, trend analysis was conducted to examine the temporal progression of agricultural resilience over the study period.

Research Framework

Figure 1 illustrates the research framework by highlighting the selected indicators that can capture the resilience of the agricultural sector in Malaysia. The selection of indicators was guided by three key considerations: (i) relevant theoretical underpinnings, including Resilience Theory, Human Capital Theory, and Innovation Theory; (ii) empirical support from prior

Figure 1 - The Framework of Agricultural Resilience Index (ARI)



Source: Developed by the authors.

studies (e.g., Siregar *et al.*, 2024; Abson *et al.*, 2012); and (iii) contextual applicability to Malaysia's agricultural sector. As illustrated in Figure 1, the research framework captures the multidimensional nature of agricultural resilience through seven core indicators: sector productivity, market performance, labour cost efficiency, innovation and technology (measured by R&D investment), labour and human capital, financial indicators, and the policy and regulatory environment. All indicators were standardised before analysis to satisfy Principal Component Analysis's (PCA) assumptions, particularly the normality requirements and equal variance contribution.

The first indicator is the Sector's Productivity. It is determined by measuring the average output produced by each worker in the agricultural sector, indicating labour productivity.

$$Agricultural\ Outputs\ Per\ Worker_t = \frac{Total\ Agricultural\ Output_t}{Number\ of\ Agricultural\ Workers_t} \quad (1)$$

Based on Eq. (1), total agricultural output is the total value of agricultural products produced within a specific period, typically measured in monetary terms. The number of agricultural workers refers to the total number of individuals employed in the agricultural sector within the same period. It

includes all types of workers, such as full-time, part-time, and seasonal, regardless of skill level.

Higher agricultural output per worker indicates greater labour productivity, which is crucial for the competitiveness and resilience of the sector. Productivity gains can lead to cost reductions, higher profitability, and the ability to offer competitive prices in international markets. According to Diao *et al.* (2010), increased labour productivity in agriculture is associated with economic growth and enhanced sectoral competitiveness, especially in developing countries where agriculture plays a significant role in the economy. Studies have shown increased productivity correlates with reduced vulnerability to economic disruptions and natural disasters (Tittonell, 2020). Therefore, a positive impact is expected from the sector's productivity towards the sector's resilience.

The second indicator is Market Performance, which is measured using the trade balance in agriculture. The difference between agricultural exports and imports indicates the sector's ability to compete internationally.

$$Trade\ Balance\ in\ Agriculture_t = Agricultural\ Exports_t - Agricultural\ Imports_t \quad (2)$$

Based on Eq. (2), agricultural exports refer to the total value of agricultural products exported from Malaysia within a specific period. The data should include all major agricultural products, including crops, livestock, fisheries, and other related goods. Agricultural imports also describe the total value of agricultural products imported into Malaysia within the same period, including all major agricultural products.

A positive trade balance (where exports exceed imports) enhances resilience by diversifying income sources and reducing dependency on domestic markets, which can be vulnerable to localised shocks. Latruffe (2010) highlighted that a favourable trade balance is a key indicator of a competitive agricultural sector as it reflects the sector's ability to produce goods that are in demand globally while maintaining cost-effective production. Furthermore, Reardon *et al.* (2019) argue that integrated value chains and market diversification act as buffers against global price volatility, enabling sectors to sustain profitability during economic downturns. Accordingly, a positive impact is expected.

The third indicator is Labour Cost Efficiency, which measures how effectively the agricultural sector uses its labour force to produce output.

$$Labor\ Cost\ Efficiency_t = \frac{Total\ Labor\ Cost_t}{Total\ Value\ of\ Outputs_t} \quad (3)$$

Based on Eq. (3), total labour cost is calculated by multiplying the average salary by the total number of agricultural workers. The input-output ratio measures the efficiency of resource use in production. A lower ratio indicates higher efficiency whereby the sector can produce more output with less input, leading to lower costs and higher competitiveness. Furthermore, efficient labour utilisation strengthens resilience by enhancing the sector's adaptability to labour market shocks. Stigler (1958) emphasised that optimising labour input during times of crisis can mitigate financial strain, ensuring continued operations and recovery. Studies on agricultural efficiency have emphasised the importance of optimising input use to enhance competitiveness, with efficient input management being a critical factor for maintaining competitive advantage in the agricultural sector (Coelli *et al*., 2005).

Innovation and technology are important indicators under investigation in this study. Investment in research and development (R&D) represents the amount of funding allocated to R&D in agriculture, thus reflecting the sector's focus on innovation. This is captured by the total R&D expenditure, which refers to all funds spent on research and development activities within the Malaysian agricultural sector. It covers public and private sector investments, including government grants, private company spending, and contributions from international organisations. Investment in R&D drives innovation, leading to the development of new technologies, improved farming practices, and higher yields. This can drive resilience by equipping the sector with tools to adapt to climate change, resource scarcity, and other challenges. For example, precision agriculture technologies and drought-resistant crop varieties have been shown to mitigate the adverse effects of extreme weather events (Fuglie, 2018). These advancements eventually increase the sector's capacity to absorb shocks and maintain productivity. The relationship between R&D investment and competitiveness/resilience has been well-documented, with studies indicating that countries with higher R&D investments in agriculture tend to be more competitive internationally (Pardey *et al*., 2006). Accordingly, a positive impact is expected from R&D towards ARI.

The fourth indicator is Labour and Human Capital. The proportion of the total labour force employed in agriculture indicates the sector's importance in the economy. Research indicates that labour force participation can significantly boost the agricultural sector's competitiveness when aligned with skill development and productivity enhancements (Martin & Mitra, 2001). High labour force participation can provide a competitive advantage if accompanied by adequate training and productivity. A skilled labour force is essential for resilience as it facilitates the adoption of new technologies and practices during crises. However, skill mismatches or an ageing workforce can reduce the sector's adaptability. Strengthening education and training

programs can bridge this gap, thus enhancing the sector's capacity to respond to shocks.

The labour force participation in agriculture can be calculated using the following formula:

$$Labor\ Force\ Participation\ in\ Agriculture\ (\%)_t = \left(\frac{Number\ of\ Agricultural\ Workers_t}{Total\ Labor\ Force_t}\right) \times 100 \quad (4)$$

Based on Eq. (4), labour force participation in agriculture refers to the proportion of the total labour force employed in the agricultural sector. The total labour force represents the total number of economically active people, including those employed in all sectors and actively seeking work. This indicator reflects the importance of agriculture in the national economy and provides insights into the availability of labour resources within the sector. Hence, a positive impact is expected.

The fifth component is Financial Indicators, which are represented by the total domestic and foreign investment in the agricultural sector. In this context, investment in agriculture is captured by the total amount of domestic credit allocated to the agricultural sector by banks and other financial institutions. Domestic credit represents the total amount of loans, advances, and other forms of credit provided by domestic banks and financial institutions specifically for agricultural purposes. Investment in agriculture is a key driver of competitiveness as it enables the sector to adopt new technologies and improve production processes, leading to greater efficiency and market success (Binswanger *et al.*, 2009). Access to credit and investment acts as a financial buffer, enabling farmers to recover quickly from economic shocks or natural disasters. For example, Agrobank's smallholder financing schemes provide critical capital for recovery and innovation (Jayne *et al.*, 2018).

The final indicator is the Policy and Regulatory Environment, which represents government financial support to the agricultural sector, such as subsidies, tax incentives, and grants. This encourages innovation and expansion within the agricultural sector. Well-designed policies can enhance resilience by reducing input costs and promoting sustainable practices. For instance, the Malaysian Palm Oil Certification Scheme (MSPO) ensures compliance with environmental standards, reducing the sector's vulnerability to trade restrictions and environmental degradation (Hamid *et al.*, 2024). Numerous studies have highlighted the role of government subsidies in enhancing the resilience of the agricultural sector by reducing input costs and supporting farmers in adopting new technologies (Orden *et al.*, 2006).

Using government expenditure on agriculture is a straightforward and effective way to measure government support. Government expenditure on the agricultural sector refers to the government's public funds for various agricultural programs and initiatives. This includes spending on subsidies, R&D, infrastructure, training, and other support forms to enhance the sector's productivity, competitiveness/and resilience. More focus and operational expenditures have been used, which refers to the day-to-day costs of running the agricultural sector. This encompasses expenses related to the maintenance of existing infrastructure, salaries of government employees in the agricultural sector, ongoing subsidy programs, and other recurring costs.

Variables and Data Sources

Table 1 presents the data used in this study and its sources.

Table 1 - Variables and Data Sources

Variable	**Unit**	**Data Source**
Total Agricultural Output	RM Million	World Bank
Number of Agricultural Workers	Thousand worker	Department of Statistics Malaysia *The agricultural industry is classified according to the "Malaysia Standard Industrial Classification (MSIC) 2008"
Agricultural Exports	RM Billion	World bank *at constant price
Agricultural Imports		
Total Labour Cost	RM Thousand	Department of Statistics Malaysia *at a constant price
Average Salary in the Agriculture Sector	RM	
Total R&D Expenditure in Agriculture	Billion	World Bank
Total Labour Force	Thousand	Department of Statistics Malaysia
Total Agricultural Credit	RM Billion	World Bank
Total Government Expenditure on Agriculture	RM Million	Ministry of Finance Malaysia

Data Analysis Techniques

Principal Component Analysis (PCA) was utilised to reduce the dimensionality of the dataset while retaining the most significant variables contributing to agricultural resilience in Malaysia. It is a popular method used to asses sector performance and resilience (e.g., Siregar *et al*., 2024). This method allows the construction of a composite measure of the sector's stability, such as investment, labour, or government spending. Among the advantages of PCA is the reduction of the complexity of the dataset by transforming it into a smaller set of uncorrelated variables known as principal components. This process is crucial for managing the multiple indicators of agricultural resilience in a manner that simplifies analysis without significant loss of information (Jolliffe & Cadima, 2016). These indicators were selected based on their relevance to agricultural resilience, as identified in the literature. Such a method identifies the most important indicators contributing to the overall variability in the data. In this study, PCA helped pinpoint the critical factors – such as investment, labour, or government spending – that contribute to the resilience of Malaysia's agricultural sector (Jolliffe, 2002). Lastly, PCA is particularly effective for constructing composite indices like the Agricultural Resilience Index (ARI). Combining the principal components, PCA provides a comprehensive measure of resilience that reflects the combined effect of all selected indicators (Jolliffe, 2002).

According to Siregar *et al.* (2024), there are six important steps for using PCA to analyse the resilience of the agricultural sector. Similar steps were followed in this study. However, PCA assumes linear relationships among variables and is sensitive to outliers, which was addressed in this study through standardisation and robust data cleaning. The data was standardised using Z-score normalisation to ensure comparability across indicators (Jiang *et al*., 2018). Such a method entails that each variable contributes equally to PCA without altering the underlying distribution of the data. This can be achieved using the following formula:

$$Z_i = \frac{X_i - \mu}{\sigma} \tag{5}$$

Where Z_i is the standardised value, X_i is the observed value, μ is the mean, and σ is the standard deviation of the data sample. The principal components were extracted based on eigenvalues greater than 1.0, and factor loadings were analysed to identify the most influential variables contributing to resilience. The cumulative variance explained by the selected components was used to assess ARI robustness.

Trend Analysis

Trend analysis was performed to assess the temporal evolution of ARI from 1996 to 2023, providing information on how the resilience of the agricultural sector has evolved. The slope of the regression line indicated the rate of change in resilience over time, while the R^2 value assessed the model's goodness of fit. The statistical significance of the trend was evaluated using p-values, ensuring robust conclusions. The trend analysis aimed to identify whether the sector has become resilient, providing insights into the effectiveness of policies and investments over the years. The results of time trend analysis can have significant policy implications. If specific trends are identified as positive or negative, policymakers can use this information to guide strategic planning, ensuring that resources are allocated effectively to enhance or maintain resilience. The regression model used to analyse the trend is given by:

$$Y = a + bX + \varepsilon \tag{6}$$

Where Y represents the ARI over time, X represents time (year), a is the intercept, b is the slope indicating the rate of change in ARI, and ε is the error term. A limitation of trend analysis is that it may oversimplify cyclical or nonlinear patterns, which was mitigated by complementing it with residual diagnostics and error metrics like Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE).

Validity and Reliability

Validity and reliability are fundamental concepts in research, particularly in data analysis studies, such as assessing agricultural resilience. These tests ensure that the results are accurate and consistent, enhancing the credibility and generalisability of the findings. Validity refers to the degree to which a research instrument measures what it is intended to measure. In the context of this study, validity ensures that the indicators and methods used (like PCA) accurately capture the concept of agricultural resilience. The validity of the PCA results was assessed using the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity. The KMO value of 0.718 indicates a middling adequacy for PCA. Meanwhile, a KMO value above 0.7 is generally considered acceptable. It can reasonably proceed with factor analysis, though the results might not be as strong as they would be with a higher KMO value (Kaiser, 1974).

On the other hand, reliability refers to the measurement's consistency over time or across different observers. A reliable instrument will yield

the same results under consistent conditions. Bartlett's test confirmed the appropriateness of the factor analysis with a significant p-value (Bartlett, 1950; Kaiser, 1974). The Chi-Square value was 187.012 with 21 degrees of freedom, and the significance level was 0.000, which is highly significant. It indicates that the correlations between variables are statistically significant and not random, thus supporting the suitability of the data for factor analysis. The significant Bartlett's test suggests adequate relationships between the variables, further justifying factor analysis.

Table 2 - KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.718
Bartlett's Test of Sphericity	Chi-square value	187.012
	Degree of freedom	21
	Significant value	0.0000

Source: Authors' calculation using SPSS.

3. Results and Discussion

Table 3 summarises the descriptive statistics of the ARI indicators over the 28-year study period to provide a basic understanding of the dataset used in this study. The mean values for Labour Cost and Innovation and Technology are 0.0188 and 0.7657, respectively. This indicates that modernising the agricultural sector by using high-tech machinery helps increase labour productivity relative to labour cost. At the same time, agricultural innovation supports the development of advanced technologies in agriculture. The ARI indicators, such as Productivity and Finance Indicators, range from 18.4990 to 102.5962 and 4.8226 to 16.2218, respectively, highlighting the dynamic nature of Malaysian agricultural resilience. Productivity (69.3426), Labour and Human Capital (13.5354), and Market Performance (9.8077) have higher medians, indicating that their contributions to resilience are slightly skewed towards higher values. These statistics provide an overview of the dynamics and distribution of the data, complementing both PCA and trend analysis.

Table 3 - Summary of Descriptive Statistics for Indicators of ARI

Indicator	Mean	Median	Maximum	Minimum	Standard Deviation
Productivity	60.95512	69.3426	102.5962	18.4990	26.0246
Market Performance	9.8077	9.3479	15.0951	1.0976	3.7529
Labour Cost Efficiency	0.0188	0.0185	0.0236	0.0131	0.0032
Innovation and Technology	0.7657	0.8687	1.4722	0.1274	0.4302
Labour and Human Capital	13.6388	13.5354	19.3611	10.2240	2.6790
Financial Indicators	9.5828	9.8250	16.2218	4.8226	2.8472
Policy and Regulation	2.9700	2.8745	5.4150	1.1210	1.4285

Source: Authors' calculation using EViews.

Table 4 shows the PCA results for selected indicators of agricultural sectors in Malaysia. Productivity obtained a factor score of 0.4470, a significant positive contributor to agricultural resilience in Malaysia. Higher productivity means the sector can produce more output with the same or fewer inputs, which is critical for sustaining its growth and resilience. For instance, while the local rice sector is vital for food security, it faces challenges with low productivity due to outdated farming techniques, poor soil fertility management, and limited mechanisation (Dorairaj & Govender, 2023). However, government programs like the Paddy Estate Model aim to consolidate small rice farms and introduce modern farming techniques to improve productivity.

Table 4 - Results from Principal Component Analysis

No.	Agricultural Sector Resilience Indicators	Factor Score
1.	Productivity	0.4470
2.	Market Performance	0.2435
3.	Labour Cost Efficiency	0.1329
4.	Innovation and Technology	0.4716
5.	Labour and Human Capital	–0.4488
6.	Financial Indicators	0.4206
7.	Policy and Regulatory Environment	0.3501

Source: Authors' calculation using EViews.

Furthermore, Malaysia's fisheries sector has seen efforts to increase productivity through sustainable aquaculture practices. For instance, the introduction of advanced aquaculture technologies and better management practices, such as the adoption of biofloc technology and automated feeding mechanisms, has improved yields in shrimp farming, which is a significant export commodity for Malaysia (Khanjani *et al*., 2023; Joffre *et al*., 2019; Department of Fisheries Malaysia, 2022). As one of the world's largest, Malaysia's oil palm sector has also seen improvements in productivity due to the adoption of better agricultural practices and improved palm oil varieties. However, there is ongoing pressure to further enhance productivity to maintain global competitiveness, particularly with the rise of Indonesia as a major producer that challenges Malaysia's position in the worldwide market (Institute of Strategic and International Studies Malaysia, 2024). While these sectors have improved productivity, continued innovation and strategic investments are essential to ensure Malaysia remains competitive and resilient in the global agricultural landscape. A study by Li *et al*. (2011) concluded that agricultural systems' resilience gradually increased as more materials and technology were accumulated, based on the significant increase in grain yield and agricultural profitability.

Market Performance obtained a factor score of 0.2435, indicating its positive influence over resilience. It reflects the importance of strong market access, favourable trade conditions, and competitive positioning in global markets. However, market performance is heavily influenced by trade relations and consumer preferences, making it essential to maintain quality and navigate trade policies effectively. For instance, Malaysia has positioned itself as a major exporter of durians, particularly the Musang King variety. The government's efforts to penetrate the Chinese market have paid off, significantly boosting the agricultural sector's income and resilience and ultimately leading to a sharp increase in demand. The export value of Malaysian durians to China reached RM887 million in 2022, and such a figure is expected to continue rising as Malaysia expands its market share in China, where durian is considered a premium product. This will be achieved by diversifying its export portfolio and reducing its dependency on traditional commodities (Malay Mail, 2024; South China Morning Post, 2023).

Furthermore, palm oil is Malaysia's leading agricultural export, contributing significantly to the country's trade balance. However, the sector faces challenges from fluctuating global prices, trade barriers, and increasing competition from other palm oil-producing countries such as Indonesia and Thailand. Despite these challenges, the strong performance of palm oil in international markets has helped sustain the sector's resilience. Malaysia's participation in trade agreements like the Comprehensive and Progressive Agreement for Trans-Pacific Partnership (CPTPP) has had mixed impacts

on agricultural market performance, providing opportunities for growth and competitive advantage while increasing competition in others (MIDA, 2020).

Meanwhile, Labour Cost Efficiency obtained a factor score of 0.1329, indicating its small yet important role in resilience. The efficient use of labour resources can help lower production costs, which is crucial for maintaining profitability in a competitive market. This aligns with the Theory of Economies Scales, which states that efficient labour utilisation reduces labour costs and contributes towards lower production costs (Stigler, 1958). In many local sectors like fruit and vegetable farming, particularly in Cameron Highlands, labour cost efficiency has been improved using drip irrigation systems and other modern farming techniques. These methods reduce the reliance on manual labour and increase efficiency, leading to better profit margins (Abdullah *et al.*, 2021). Interestingly, the Malaysian tea industry, particularly in Cameron Highlands, has gradually shifted towards mechanisation to improve labour cost efficiency. However, the high cost of machinery and the steep terrain present challenges to widespread mechanisation, making labour cost efficiency an ongoing issue.

Malaysia's agricultural sector heavily relies on foreign labour, particularly in plantations like palm oil. For instance, the Malaysian palm oil sector reported a shortage of approximately 40,000 foreign workers in 2024. It significantly impacted production, leading to an estimated loss of RM7.9 billion in export value due to the unharvested fresh fruit bunches (FFB) (New Street Times, 2024). This reliance has led to concerns about labour cost efficiency, especially when considering rising labour costs, dependency on low-skilled labour, and challenges in mechanisation. Efforts to improve labour cost efficiency through mechanisation have been slow, particularly in smallholder farms. The government has initiated programs to encourage technology adoption, but the high cost of mechanisation remains a barrier.

The PCA results also showed that Innovation and Technology are Malaysia's most significant contributors to agricultural resilience, with a factor score of 0.4716. It emphasises the importance of adopting new practices and technologies to stay competitive and sustainable. The Malaysian government has been promoting smart farming practices that integrate the Internet of Things (IoT), data analytics, and automation. For instance, IoT sensors are used in the chicken farming industry to monitor temperature, humidity, and feed levels in real-time, thus optimising conditions for better productivity and reduced losses. A study by Hidzir and Ismail (2022) explored the implementation of IoT in poultry farming and found that IoT-based monitoring systems, which include sensors for temperature and humidity alongside automated feeding mechanisms, help maintain optimal conditions in chicken coops. This leads to better growth rates and reduced mortality, ultimately contributing to higher productivity and profitability

in the sector. Additionally, the integration of agroforestry practices, where trees are grown alongside crops or livestock, has been gaining attention in Malaysia. This method diversifies farmers' income streams and improves soil health and resilience against climate change impacts.

Furthermore, Malaysia has invested in precision agriculture technologies, such as drones, IoT sensors, and data analytics, to optimise crop yields and reduce resource use. For example, drone technology is increasingly used in palm oil plantations for monitoring and precision spraying, significantly boosting productivity and sustainability (Ismail, 2024). The Malaysian Agricultural Research and Development Institute (MARDI) has been at the forefront of agricultural innovation by focusing on developing high-yield crop varieties, sustainable farming practices, and biotechnology advancements. Therefore, Malaysia is moving in the right direction in adopting and enhancing innovation and R&D in the agricultural sector to create sustainability and resilience.

Interestingly, Labour and Human Capital had a factor score of -0.4488, indicating its negative impact on the resilience of Malaysia's agricultural sector. This might be attributed to challenges like skill mismatches, ageing workforces, and possibly a lack of training in new technologies. This is contradicted by the prediction that a positive impact is expected, which can be linked to structural reforms and labour emigration from one sector to another. For instance, the local cocoa sector faces significant challenges due to an ageing farmer population, with many young people opting for jobs outside agriculture (Malay Mail, 2023). This has decreased production as older farmers are less likely to adopt new techniques that could improve yields. Siregar *et al.* (2024) found that agricultural workers' income strongly correlates with ARI, followed by NTUP, total credit, investment, government spending, and trade. In contrast, a higher proportion of agricultural workers in total labour tends to lower resilience. This shows that agricultural workers hurt ARI, which is equivalent to our study.

There is also a growing recognition of skills mismatch in Malaysia's agribusiness sector (Howell, 2022). Many agricultural workers lack the technical skills to operate modern machinery or apply new farming techniques, which hampers productivity and innovation. The local agricultural sector faces a significant challenge with an ageing workforce. Young people are increasingly reluctant to enter farming, leading to a lack of skilled labour and a declining workforce, negatively impacting the sector's resilience. Reports indicate that only 15% of youth are involved in the agriculture business in Malaysia (BusinessToday, 2021, 2023). Despite the government's efforts to enhance agricultural education and training, there remains a gap in skills and knowledge, particularly in adopting

new technologies. This gap reduces the effectiveness of human capital in contributing to resilience.

Next is Financial Indicators, with a factor score of 0.4206. Financial factors are crucial for resilience, highlighting the importance of access to credit, investment, and financial stability in the agricultural sector. Smallholders in the palm oil and rubber sectors often struggle to access finance due to stringent loan conditions. However, initiatives like Agrobank's financing schemes for smallholders aim to bridge this gap, enabling farmers to invest in improvements that can enhance resilience. Malaysia's implementation of the Halal Industry Master Plan 2030 (HIMP 2030) aimed to enhance industry competitiveness, expand markets, and develop a pool of halal experts to meet global demand. The initiative attracted significant investment in the halal food industry, providing financial support for businesses to expand and innovate (MIDA, 2023). This financial backing is crucial for maintaining the sector's growth and resilience against global competition.

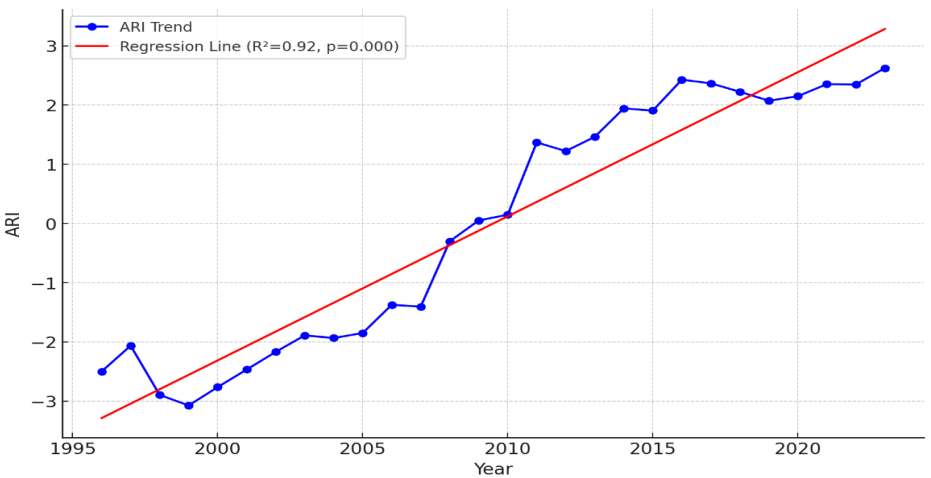
The Malaysian government has provided various financial incentives to support farmers and agribusinesses, including subsidies and grants such as the Young Agropreneur Grant and Halal Industry Development Grant. These financial supports are crucial for maintaining productivity and enabling the adoption of new technologies. However, smallholders often face difficulties accessing finance due to stringent requirements and limited collateral. This limits their ability to invest in improvements, making them more vulnerable to economic shocks.

Lastly, the Policy and Regulatory Environment obtained a factor score of 0.3501, indicating its positive influence on resilience. Well-crafted policies can significantly enhance the sector's capacity to adapt and thrive. The Ministry of Finance Malaysia reported that the government allotted RM2.6 billion in fertiliser subsidies for paddy farmers to reduce production costs and boost productivity (Ministry of Finance Malaysia, 2023). This policy helps sustain the rice sector's resilience by ensuring farmers can afford essential inputs. Furthermore, Malaysia has implemented sustainable fisheries policies to combat overfishing and protect marine biodiversity. These policies include quotas, seasonal bans, and the promotion of aquaculture as an alternative to wild-capture fisheries. Such regulatory measures will ensure the long-term sustainability and resilience of the fisheries sector. Implementing the MSPO certification has helped improve the sustainability of palm oil production in Malaysia, enhancing the sector's resilience by ensuring compliance with environmental and social standards. Furthermore, regulatory policies related to land use, such as converting agricultural land for industrial purposes, have a mixed impact on resilience. While these policies can drive economic diversification, they also reduce the availability of land for agriculture,

potentially weakening the sector's resilience. This is supported by Qun *et al.* (2024), who highlighted that agricultural science and technology innovation have a nonlinear and significant positive effect on agricultural resilience, which relevant fiscal policies can further support.

In summary, the factor analysis revealed that innovation and technology, productivity, and financial support are crucial drivers of agricultural resilience across various sectors in Malaysia. However, labour and human capital challenges, market dynamics, and policy implementation must be addressed to enhance the sector's overall resilience. Diversifying the focus to include different agricultural sectors, such as rice, fisheries, rubber, and fruit farming, provides a more comprehensive understanding of the factors influencing resilience in Malaysia's agricultural landscape.

Figure 2 - The Agricultural Resilience Index (ARI) Trend of Malaysia's Agricultural Sector



Source: Illustrated using EViews.

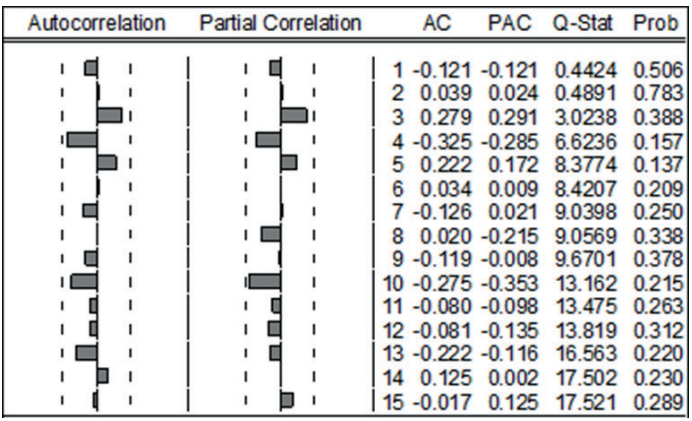
Figure 2 shows the ARI trend in Malaysia's agricultural sector from 1996 to 2023. A clear upward trend can be observed in the ARI values, and the regression line fitted to the data has a positive slope of approximately 0.24. This indicates that, on average, the ARI value increases by 0.24 units yearly. Meanwhile, the slope of the regression line represents the rate at which ARI changes each year. The slope of 0.24 suggests that ARI has steadily increased over the 28 years. This positive slope suggests a consistent upward movement in ARI, which might imply an increasing frequency of the event or metric being measured by ARI, depending on its specific definition.

The R^2 value of 0.92 is very high, indicating that the regression model explains about 92% of the variance in ARI values. This means the trend is strong, and the ARI values closely follow a linear pattern over time. In simpler terms, the year-to-year changes in ARI are primarily predictable based on the time variable alone. The p-value associated with the regression line is extremely small (i.e., 0.0000), indicating that the upward trend is statistically significant. This means that the observed increase in ARI over time is unlikely due to random variation; instead, it reflects a real, underlying pattern.

As shown in Figure 2, the ARI values began in negative territory (e.g., –2.498 in 1996) and gradually increased, crossing into positive territory around 2008 (0.05) and continuing to rise after that. By 2023, the ARI value was 2.62, showing substantial growth. This upward trend could indicate the increasing frequency or severity of the events or conditions ARI measures. For example, if ARI is related to environmental factors, this might suggest worsening conditions or more frequent occurrences of a particular phenomenon over time. It would be important to consider external factors or events that could have influenced the ARI values during the period. For example, policy changes, technological advancements, or significant global events might have contributed to shifts in the trend. In parallel, R&D investments showed gradual increases, particularly in the 2010s, driven by government initiatives like the National Agrofood Policy and increased allocations for agricultural research under Malaysia's Five-Year Plans. These investments facilitated the adoption of precision agriculture, biotechnology, and sustainable farming practices, which are reflected in the upward ARI trend. Despite these improvements, some periods, such as the late 1990s Asian financial crisis, witnessed a decline in resilience. This underscores the sensitivity of agricultural systems to economic shocks, even in the presence of R&D investments. Furthermore, the challenges in the early 2020s, such as labour shortages exacerbated by the COVID-19 pandemic, highlight ongoing vulnerabilities despite technological advancements.

The robustness of ARI was evaluated using ACF and PACF tests and reported in Figure 3. These tests assessed the presence of serial correlations in the residuals and provided insights into the short-term dependencies within the data. The analysis was conducted in differencing to achieve stationarity (Lin *et al*., 2023). The ACF results suggest that the residuals exhibit low dependencies over time. This finding supports the assumption that ARI adequately captures the underlying trends in agricultural resilience without significant autocorrelation. Similarly, the PACF results indicate that the ARI's construction minimises direct relationships with lagged terms. The combined results of the ACF and PACF tests validate the robustness of the trend analysis by confirming the absence of systematic patterns or dependencies that could compromise the reliability of ARI.

Figure 3 - The Autocorrelation (ACF) and Partial Correlation Function (PACF) Test Results for Agricultural Resilience Index in Malaysia



Source: Illustrated using EViews.

Table 5 - Diagnostic Test Results for Agricultural Resilience Index Trend Analysis in Malaysia

Normality Test (Jarque-Bera)	3.3187 (0.1903)
Heteroskedasticity Test (Breusch-Pagan-Godfrey)	0.0489 (0.8268)

Source: Authors' calculation using EViews.

Diagnostic tests were conducted to assess normality and heteroskedasticity and further validate the robustness of the ARI trend analysis in Malaysia. The results are summarised in Table 5. The Jarque-Bera Normality Test yielded a test statistic of 3.3187 with a p-value of 0.1903, indicating that the residuals do not significantly deviate from a normal distribution. This supports the assumption of normality, which is critical for ensuring the reliability of the trend analysis and interpreting subsequent inferential statistics. The Breusch-Pagan-Godfrey Heteroskedasticity Test produced a test statistic of 0.0489 with a p-value of 0.8268, suggesting no evidence of heteroskedasticity in the residuals. This confirms that the variance of the residuals remains constant across observations, thereby validating the homoscedasticity assumption of the model.

Table 6 - Mean Absolute Error (MAE), Mean Squared Error (MSE), and Root Mean Squared Error (RMSE) Analysis Results for Agricultural Resilience Index Trend in Malaysia

Mean Absolute Error (MAE)	0.2517
Mean Squared Error (MSE)	0.0804
Root Mean Squared Error (RMSE)	0.2835

Source: Illustrated using EViews.

Lastly, Table 6 presents the error metrics used to evaluate the accuracy and robustness of the ARI trend analysis in Malaysia. The MAE, MSE, and RMSE quantitatively assess the model's performance (Gomez *et al*., 2024; Praveenkumar *et al*., 2024). The MAE, calculated at 0.2517, indicates that, on average, the model's predictions deviate from the actual values by approximately 0.25 units. This reflects a relatively low error level, demonstrating the model's accuracy in capturing the dynamics of agricultural resilience (Akbari *et al*., 2024).

The MSE, which is reported as 0.0804, indicates the average squared deviation between predicted and actual values. The small magnitude of the MSE highlights the model's ability to minimise significant prediction errors, which is critical for maintaining reliability in long-term trend analysis. The RMSE, derived as 0.2835, represents the typical magnitude of prediction errors in the same units as ARI. The slightly higher RMSE value than MAE suggests that significant outliers or extreme deviations do not significantly impact the model (Hassanat *et al*., 2023).

These error metrics confirm that the trend analysis provides reliable predictions of ARI with minimal errors. The results align with other diagnostic tests conducted in this study, further supporting the robustness and validity of the methodological framework.

Conclusions

The resilience of Malaysia's agricultural sector is crucial for ensuring the nation's food security, economic stability, and sustainable development amidst the mounting global and local challenges. This study has developed an Agricultural Resilience Index (ARI) to provide a comprehensive measure of resilience by incorporating multiple dimensions, such as economic stability, technological innovation, environmental sustainability, and social adaptation. By employing PCA and trend analysis, the study offers valuable insights into

the indicators that influence resilience and the trends that have shaped the sector's performance over the past few decades.

The findings of this study highlight the significant role of research and development (R&D) investments in enhancing agricultural resilience. R&D has proven to be a key driver of innovation and productivity, facilitating the adoption of advanced technologies and practices that enable the agricultural sector to adapt to changing environmental and economic conditions. The positive correlation between R&D investments and resilience underscores the importance of sustained and targeted investments in this area to ensure the long-term viability of Malaysia's agriculture.

Furthermore, the study revealed important trends in agricultural resilience, showing how various factors, such as government policies, market conditions, productivity, and labour efficiency, have impacted the sector over time. These trends indicate that while Malaysia's agricultural sector has made considerable progress in certain areas, significant challenges remain, particularly in addressing the impacts of labour productivity shortages and market volatility.

This study also offers policy-relevant insights to enhance the resilience of Malaysia's agricultural sector. The substantial impact of innovation and finance on resilience highlights the urgency of sustained investment in agricultural R&D, innovative technologies, and inclusive financing mechanisms. These findings align with the National Agrofood Policy 2.0 (NAP 2.0), particularly under Policy Thrust 1, which aims to modernise the agro-food sector through structured R&D efforts, particularly by accelerating the development of resilient crop varieties, enhancing agro-innovation ecosystems, and increasing public-private partnerships.

Meanwhile, workforce development strategies must be intensified to address the negative impact of labour and human capital on resilience. NAP 2.0's Policy Thrust 3 emphasises TVET expansion, youth agropreneur training, and automation incentives to modernise the agricultural workforce. Specific action plans such as developing model farms and providing training infrastructure can increase the adoption of precision technologies among smallholders. Moreover, resilience strategies should consider spatial variation. NAP 2.0 advocates for regionalised approaches such as agro-based economic zones and controlled-environment farming to support high-value production tailored to local conditions. Community farming initiatives and agro-cluster linkages are also vital to facilitate inclusive growth. Aligning national strategies with the findings of this study will enable Malaysia to build a resilient, competitive, and sustainable agro-food system in line with its Shared Prosperity Vision 2030 and the Sustainable Development Goals (SDG, 2030).

While this study provides a robust analysis, several limitations must be acknowledged. The PCA approach assumes linear relationships and

orthogonal principal components, which may oversimplify complex interactions among variables. Additionally, long-term secondary data may contain inconsistencies or estimation modifications from a few data sources. Moreover, the ARI is constructed nationally and does not reflect sub-national differences, such as disparities between Peninsular Malaysia and East Malaysia. Future research should incorporate spatial econometric techniques and qualitative fieldwork to capture more granular insights. Similarly, incorporating variables related to institutional quality, farmer perception, and agro ecological diversity could enrich the ARI framework.

In conclusion, this study contributes to the growing body of literature on agricultural resilience by providing a detailed assessment of Malaysia's agricultural sector and offering practical recommendations for enhancing its resilience. As global and local challenges continue to evolve, the insights gained from this research can guide policymakers, researchers, and stakeholders in developing strategies to ensure the sustainability and resilience of Malaysia's agriculture for future generations. This study makes a novel contribution by constructing a comprehensive and longitudinal Agricultural Resilience Index (ARI) specific to Malaysia. By integrating technological, economic, labour, policy, and market dimensions, this study presents a replicable framework for resilience assessment in other developing countries. Unlike prior studies that focused on short-term shocks or single factors, this research provides a multi-dimensional and temporal analysis, revealing the drivers of resilience across nearly three decades. It offers empirical evidence that resilience is not static but can be cultivated through sustained policy support, innovation, and investment.

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Evaluation of Food Quality Attributes Influencing Generation Z's Consumer Preferences for Packaged Beverages

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Abstract

The packaged beverage industry has experienced significant growth globally, driven by advancements in packaging technology, shifting consumption patterns, and increasing health and environmental regulations. This study investigates Generation Z's perception of packaged beverage quality by examining how intrinsic and extrinsic attributes influence their preferences using Caswell's framework. Data were collected via an online questionnaire completed by 300 purposively selected respondents. Descriptive statistics, crosstab analysis, and factor analysis were used to explore consumer behavior patterns. Results show that sensory qualities, certifications, and price are the most influential factors. Socio-demographic variables such as gender, income, education, and residence significantly affect attribute prioritization. Factor analysis revealed three key dimensions: intrinsic credence (including safety, nutrition, processing methods, and certifications), extrinsic (including advertising, producer reputation, and packaging), and intrinsic search (including sensory qualities, price, and perceived value). These findings provide practical insights for tailoring product development, marketing strategies, and health-oriented policies to meet Generation Z's expectations. The study offers a theoretical contribution to consumer behavior research by refining quality perception models through a multi-attribute lens.

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Introduction

The packaged beverage industry, encompassing products such as sweet tea, sweet coffee, soft drinks, and similar beverages, has experienced significant global growth in recent years. This growth has been driven by innovations in packaging technology, shifting consumption patterns, and increasingly stringent health and environmental regulations. Recent reports estimate that the market for packaged beverages will expand from approximately $157.73 billion in 2023 to $222.08 billion by 2030, representing a compound annual growth rate (CAGR) of 5.0% (Baranidharan *et al.*, 2024; Grand View Research, 2024; Smedescu *et al.*, 2024).

Parallel to this growth, consumers are placing increasing importance on product quality attributes, including labeling, health claims, certifications, pricing, and nutritional content. These evolving preferences are largely influenced by heightened health consciousness and demand for transparency in food and beverage products. As a result, public health policies have gained a central role in shaping market dynamics – particularly through efforts to regulate sugar content and promote healthier choices. To guide consumers toward healthier products, many countries have introduced front-of-pack (FOP) nutrition labeling systems. These initiatives have demonstrated strong impacts on purchasing behaviors, with consumers tending to prefer lower-sugar products (Cecchini & Warin, 2016; Hoenink *et al.*, 2021; Kelly & Jewell, 2019; Vandevijvere *et al.*, 2020).

Color-coded and warning-based nutritional labels have also proven effective in raising consumer awareness of the health risks associated with high-sugar beverages, thus fostering healthier consumption habits (Song *et al.*, 2021). Countries like Australia and New Zealand have implemented the Health Star Rating (HSR) system, which has guided nutrition-conscious consumers toward healthier food and beverage choices, while the United Kingdom's traffic light labelling provides clear visual indicators of a product's nutritional quality, facilitating informed decision-making (Kunz *et al.*, 2020; Söderlund *et al.*, 2020). These regulatory efforts not only empower consumers with essential nutritional information but also encourage manufacturers to reformulate their products to meet health standards, thereby enhancing the overall quality of packaged beverages available in the market (Cecchini & Warin, 2016; Crockett *et al.*, 2018).

Beyond labelling initiatives, fiscal policies such as taxation on sugary beverages have been widely adopted as a strategy to curb the consumption of unhealthy drinks. Some countries have demonstrated that such measures can effectively reduce the purchase of high-sugar beverages while simultaneously generating revenue for public health programs (Acton & Hammond, 2018; Colchero *et al.*, 2021; Mialon *et al.*, 2021; Taillie *et al.*,

2020). Moreover, in response to growing consumer concerns over food safety and quality, countries like China have implemented agri-food traceability systems, enhancing transparency within the food supply chain and reducing information asymmetries. These systems not only build consumer confidence in the quality attributes of packaged beverages but also address heightened demand for traceable and high-quality products (Liu *et al.*, 2023).

To better understand how consumers evaluate food product quality, Caswell's consumer perception model offers a foundational classification of quality information (Figure 1). Building on Steenkamp's quality perception framework (Steenkamp, 1990), this framework distinguishes when and how consumers can assess specific product characteristics – whether prior to purchase (search), during or after consumption (experience), or in cases where verification remains difficult even after use (credence) (Caswell, 2000; J. A. Rodriguez *et al.*, 2021). It illustrates how a consumer's expected quality emerges from multiple influences, including past experiences, education, perceived risks, and environmental factors. In the context of product innovations – particularly in the beverage sector – which further classifies quality attributes into intrinsic and extrinsic types (Figure 2). Intrinsic attributes, such as sensory characteristics, nutritional value, safety, and processing methods, reside in the product's physical composition and are

Figure 1 - Food quality framework (Caswell, 2000)

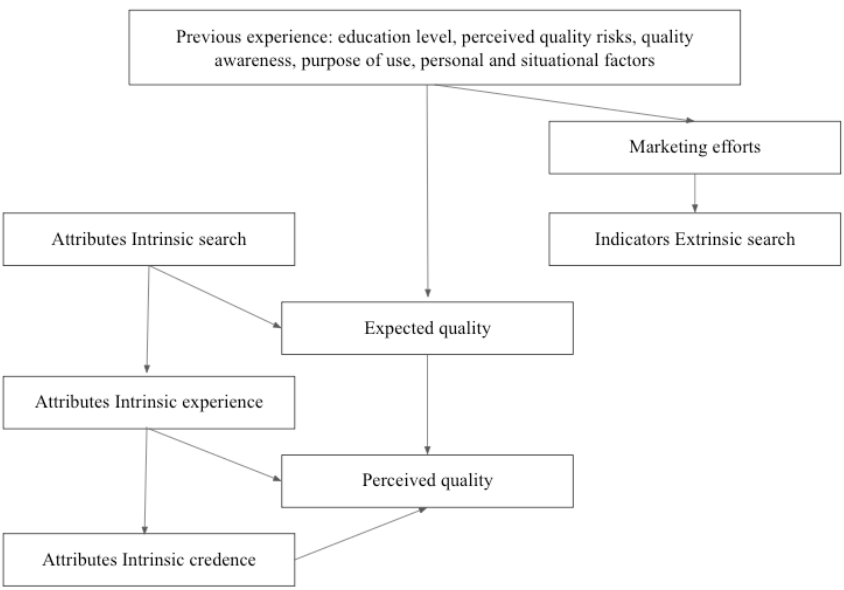
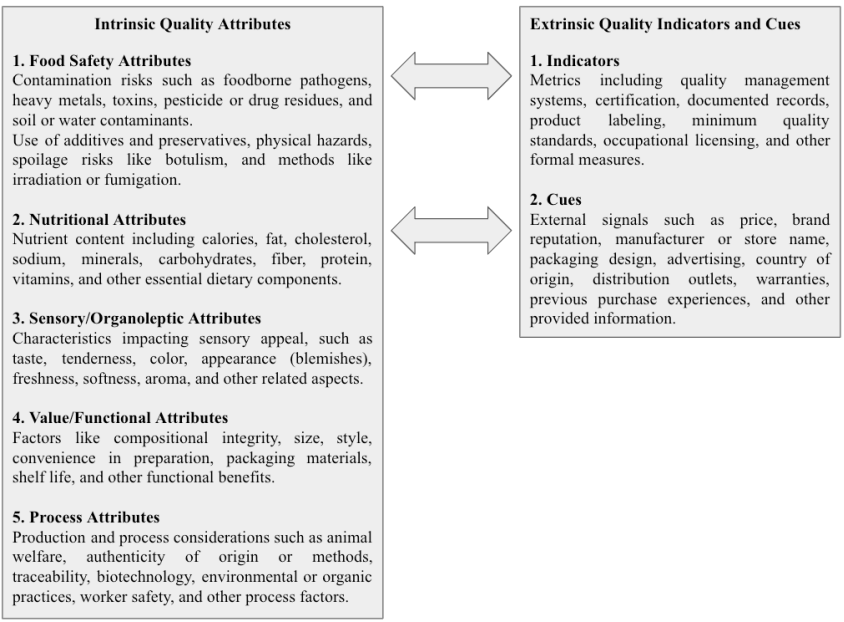


Figure 2 - Food intrinsic attributes and extrinsic indicators and cues (Caswell & Mojduszka, 1996)



filtered through consumers' informational environments. By contrast, extrinsic attributes – including packaging, cultural relevance, labelling, and market accessibility – reflect elements shaped by marketing strategies (Caswell & Mojduszka, 1996).

Taken together, these intrinsic and extrinsic considerations shape both consumer perception and ultimate decision-making, providing a comprehensive lens through which producers can better understand and meet evolving market demands. Studies based on experimental methods – such as Vickrey second-price auctions – further highlight how labelling (e.g., GMO/non-GMO or low pesticide content), nutritional information, and clear packaging can notably shift consumer judgments of healthfulness and willingness to pay (A. G. Rodriguez *et al.*, 2023; J. A. Rodriguez *et al.*, 2021). In other words, clear communication of product attributes is central to harmonizing what consumers expect and what they ultimately experience, thereby enhancing both trust and acceptance in new food and beverage innovations.

Although prior studies have examined the impact of these attributes on general consumer behaviour, there remains a lack of focused research

on Generation Z – a digitally native, health-aware, and socially conscious demographic born between 1997 and 2012. This generation has emerged as an influential consumer segment within the packaged beverage industry. This demographic exhibits distinct consumption patterns, characterized by a strong preference for products that are healthy, eco-friendly, and locally sourced. Generation Z consumers are particularly drawn to brands that demonstrate a commitment to sustainability, often influenced by social media platforms where they discover, engage with, and evaluate new products and trends (Djafarova & Foots, 2022; Tan & Trang, 2023). Their purchasing decisions are further shaped by a demand for convenience and experiential consumption, favouring products that provide immediate satisfaction and align with their dynamic, fast-paced lifestyles (Chen *et al.*, 2024). Additionally, urgency-driven marketing strategies, such as the "Buy Now, Think Later" concept, have been shown to increase impulsive purchasing tendencies among Gen Z consumers. These insights highlight the impact of marketing tactics on the consumption behaviors of younger demographic (Chairunnisah *et al.*, 2024).

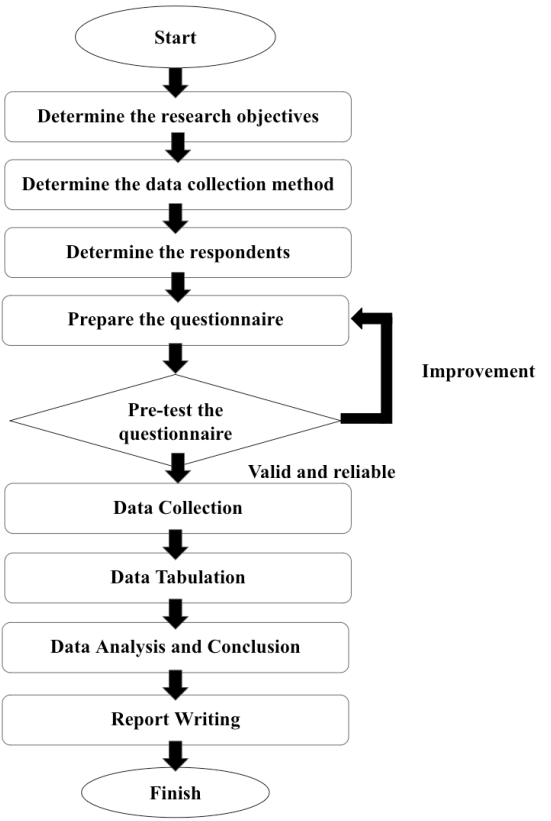
This study aims to fill that gap by examining the quality attributes that influence Generation Z's preferences for packaged beverages, such as sweet tea, sweet coffee, and soft drinks, commonly available in supermarkets. By integrating Caswell's frameworks with Gen Z's unique consumer behaviours, the study provides valuable insights for producers and policymakers seeking to align product strategies and regulations with market expectations.

1. Materials and Methods

1.1. *Study design and context*

This study used a quantitative, cross-sectional survey design which sample selection was conducted October 2024. The respondents were Generation Z in Indonesia, defined as individuals born between 1997 and 2012, who represent about 26.4% of the national population, or roughly 71.5 million people (BPS-Statistics Indonesia, 2021). Indonesian Generation Z was selected due to its growing youth demographic, rapid digitalization, and expanding packaged beverage market (IDN Research Institute, 2024), making it a relevant setting to examine consumer behaviour among young adults. The complete research stages are illustrated in Figure 3.

Figure 3 - Flowchart of the stages of consumer preferences survey research



1.2. *Questionnaire development*

The questionnaire was developed to measure consumer preferences toward quality attributes in packaged beverage products, guided by Caswell's classification of food quality (Caswell & Mojduszka, 1996). Caswell's original framework distinguishes between intrinsic and extrinsic product attributes. For this study, the framework was adapted specifically for packaged beverages to enhance its contextual relevance to the Indonesian Generation Z market. Intrinsic attributes were grouped into five subcategories: food safety, nutrition, sensory characteristics, value, and processing methods. Extrinsic attributes were categorized into corporate-related and informational dimensions, which include elements such as branding, producer reputation, labeling, and certifications.

The instrument itself was divided into two main sections: the first focused on respondent identity, collecting demographic information such as name,

gender, education level, and income; the second section examined consumer motivations and preferences related to a wide range of quality dimensions in packaged beverages. To capture the multidimensional nature of consumer perception, the questionnaire combined various question types – open-ended, closed-ended, semi-closed, and Likert scale items – to allow respondents to express both structured preferences and more personalized opinions. Quality attributes were rated using a 5-point Likert scale ranging from "very unimportant" to "very important," while semi-open questions enabled respondents to provide custom answers beyond the listed options.

1.3. *Pilot testing (pre-test) and instrument validation*

Before launching the full survey, a pilot test was conducted involving 33 participants from the target population – Indonesian Generation Z with prior experience consuming packaged beverages such as sweet tea, sweet coffee, soft drinks, and similar supermarket products. The pilot aimed to evaluate the clarity, structure, response time, and overall comprehensibility of the questionnaire. Based on the feedback received, several Likert-scale items were revised due to perceived redundancy, and unclear terms such as "process attributes" and "certifications" were reworded using simpler and more familiar language. The form's layout was also optimized for mobile compatibility to enhance user experience, and the average completion time of 9-12 minutes was deemed acceptable by participants. A detailed breakdown of the questionnaire content, along with adjustments made based on the pilot feedback, is provided in Table 1.

To ensure the instrument accurately assessed consumer preferences for quality attributes in packaged beverages, the questionnaire was tested for validity using Spearman's rank correlation coefficient (Equation 1) and for reliability using Cronbach's alpha (Equation 2).

$$r_s = 1 - \frac{6\Sigma b_i{}^2}{n(n^2 - 1)} \quad (1) \qquad \alpha = \left(\frac{k}{k-1}\right)\left(\frac{1 - \Sigma\sigma_i{}^2}{\sigma_x{}^2}\right) \quad (2)$$

Where:

- r_s: Spearman rank correlation coefficient
- b_i^2: The squared difference between one ranking and another
- n: The number of observations (respondents)

Where:

- α: Cronbach's alpha coefficient (reliability coefficient)
- k: The number of valid questions
- $\Sigma\sigma_i^2$: The total variance of the valid question items
- σ_x^2: The variance of the total score

Table 1 - List of questions in the questionnaire

Section	Code	Question	Type
Respondent Identity	A1	Name	Open-ended
	A2	Residence	Closed-ended
	A3	E-mail	Open-ended
	A4	Gender	Closed-ended
	A5	Education Level	Semi-open
	A6	Income Level	Closed-ended
Product Quality	B1	Main considerations for food product choice	Semi-open
	B2	Importance level of quality attributes	Closed-ended (Likert scale)
	B3	Food safety attributes	Closed-ended
	B4	Nutrition attributes	Closed-ended
	B5	Sensory attributes	Closed-ended
	B6	Value attributes	Closed-ended
	B7	Informational attributes	Closed-ended
	B8	Process attributes	Closed-ended (Likert scale)
	B9	Corporate management attributes	Closed-ended (Likert scale)

1.4. *Sampling and data collection procedure*

This study targeted individuals who actively use internet and e-mail services and had prior experience consuming packaged beverages, such as sweet tea, sweet coffee, soft drinks, and similar supermarket products. Participants were selected using a purposive sampling technique – a non-probability method where individuals are deliberately chosen based on specific inclusion criteria relevant to the research objectives (Usman & Akbar, 2008; Victoria Sepulveda, 2009). In this case, eligibility was based on respondents' experience with packaged beverage consumption, aligning with the study's focus on Generation Z consumer behavior.

To determine the required minimum sample size, Cochran's formula was applied (Cochran, 1991). Using a Z-score of 1.96 for a 95% confidence level, a population proportion of 0.264 (representing the proportion of Generation Z in Indonesia) (BPS-Statistics Indonesia, 2021), and a margin of error of 5% ($\alpha = 0.05$). The result indicated a minimum sample of approximately 299 respondents, as shown in Equation (3).

$$n = \frac{Z^2 \,.\, p(1-p)}{\alpha^2} = \frac{(1.96)^2 \,.\, 0.264\ (1 - 0.264)}{0.05^2} = 298.64 \approx 299 \text{ respondents} \quad (3)$$

The online questionnaire was developed and distributed using Google Forms, providing a convenient and accessible platform for digital data collection. To minimize sampling bias and self-selection bias – issues commonly associated with open online surveys (Andrade, 2020) – the survey link was not made publicly available. Instead, it was strategically disseminated through e-mail invitations to curated mailing lists and youth-focused digital communities relevant to Indonesian Generation Z. This controlled distribution method helped prevent uncontrolled responses and reduce the risk of sampling errors while also ensuring that participants met the study's eligibility criteria (Verster *et al.*, 2010). Moreover, this approach successfully captured a wide range of socio-demographic diversity, as reflected in Tables 2 and 3.

Table 2 - Representative socio-demographic characteristics of the sample (% of respondents, N = 300)

Socio-demographic Categories		**Sample**	**Population**
Gender	Woman	48.67	48.55
	Man	51.33	51.45

Note: Ratio in the population according to the latest census (BPS-Statistics Indonesia, 2021).

Table 3 - Further socio-demographic characteristics of the sample (N = 300)

Socio-demographic Categories		**Sample (N)**	**Percentage (%)**
Type of Residence	Rural	143	47.67
	Urban	157	52.33
Education	Other education (primary, secondary, etc)	44	14.67
	Higher education	256	85.33
Level of income	Low (< IDR2.500.000/month)	84	28.00
	Average (IDR2.500.000-5.000.000/ month)	205	68.33
	High (>IDR 5.000.000/month)	11	3.67

1.5. *Data analysis*

The data were analyzed using descriptive and inferential statistics. Descriptive analysis summarized demographic profiles and multiple-choice responses using tables and graphs, while crosstab analysis explored associations between socio-demographic factors and preferences for quality attributes. To identify underlying dimensions of perceived quality, factor analysis was used to reduce multiple observed variables into a few latent factors.

As factor analysis requires interval-scale data, ordinal responses from Likert scales were first transformed using the Method of Successive Intervals (MSI) – a psychometric approach that converts ordinal data into interval values by applying z-score transformations based on cumulative response probabilities (Asdar & Badrullah, 2016). Factor analysis proceeded in two stages: a feasibility test using the Measure of Sampling Adequacy (MSA), excluding variables with MSA < 0.5, followed by factor extraction. All analyses were performed using IBM SPSS Statistics 25.

2. Results and Discussion

2.1. *Questionnaire validity and reliability*

The validity of the questionnaire was evaluated using the Spearman rank correlation on 19 variables. A variable was deemed valid if the calculated rs value exceeded the rs table value at a 5% significance level. For n = 33 and df = 31, the rs table value was 0.344. Reliability was evaluated using Cronbach's alpha, with a value greater than 0.70 considered the minimum acceptable threshold for scale reliability, while values exceeding 0.80 are regarded as ideal (Yu *et al.*, 2022). The results, as shown in Tables 4 and 5, confirm that all items in the questionnaire are both valid and reliable.

Table 4 - rs calculated values for each test variable

No	Test Variable	Rs Value	No	Test Variable	Rs Value
1	Safety	0.375*	11	Origin	0.803*
2	Nutrition	0.463*	12	Biotechnology	0.800*
3	Sensory	0.403*	13	Organic	0.711*
4	Value	0.446*	14	Handling	0.868*
5	Process	0.479*	15	BPOM	0.629*

No	Test Variable	Rs Value	No	Test Variable	Rs Value
6	Certification	0.436*	16	Halal	0.435*
7	Packaging	0.510*	17	HACCP	0.856*
8	Price	0.379*	18	GMP	0.808*
9	Producer	0.494*	19	Reputation	0.430*
10	Promotion	0.559*			

* Correlation is significant at the 0.05 level (2-tailed).

Table 5 - Reliability test results using Cronbach's alpha

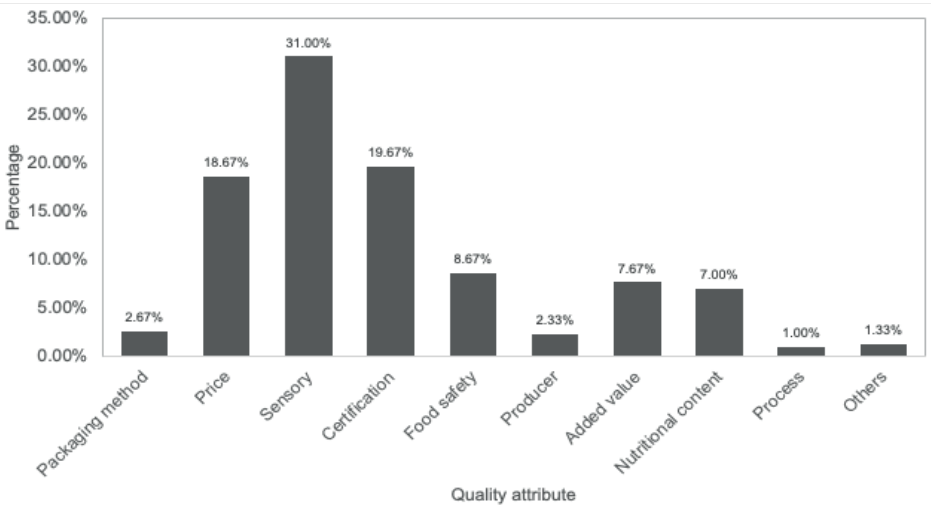
Cronbach's alpha	N of items
0.813	19

2.2. *Key Quality Attributes in Packaged Beverage*

Key quality attributes in packaged beverages are the critical factors that shape consumer preferences and influence their purchasing decisions. These attributes encompass sensory aspects like taste, aroma, and texture, as well as certifications (e.g., Halal or quality assurance), price, food safety, nutritional value, packaging, producer reputation, added benefits, and production methods. According to Figure 4, sensory attributes are the most influential, accounting for 31.00% of consumer preferences, followed by certifications (19.67%) and price (18.67%). The sensory properties of beverages, including taste and aroma, significantly impact consumer acceptance and preference. Research indicates that consumers are highly sensitive to these attributes, which can dictate their choices in a competitive market (Liu *et al.*, 2021). Additionally, the packaging design plays a crucial role in enhancing the sensory experience. For instance, studies employing Kansei engineering demonstrate that attractive packaging can evoke positive emotional responses, thereby influencing consumer perceptions and decisions (Chang *et al.*, 2018; Pratiwi *et al.*, 2023).

Furthermore, the visual appeal of packaging, including color and design, can also affect consumer behavior, as it serves as a critical cue for quality assessment (Lindh *et al.*, 2016). Certifications such as Halal and quality assurance labels are increasingly important to consumers, particularly in diverse markets where dietary restrictions and health considerations are paramount. These certifications not only assure consumers of the product's compliance with specific standards but also enhance trust in the brand

Figure 4 - The key of Gen Z consumer considerations percentage for quality attributes in packaged beverage



(Dlamini *et al.*, 2024). Price remains a significant factor, as consumers often weigh the perceived value against their willingness to pay, which can be influenced by the packaging and branding strategies employed by producers (Poelman *et al.*, 2016). Moreover, the nutritional value of beverages is becoming a focal point for health-conscious consumers. Studies have shown that consumers are increasingly aware of the sugar content and overall health implications of their beverage choices, leading to a demand for products that align with healthier dietary practices (Wen *et al.*, 2021). This trend is evident in the growing popularity of functional beverages that offer added health benefits, which cater to the evolving preferences of consumers seeking both convenience and nutritional value (Corbo *et al.*, 2014).

Table 6 highlights that certification, safety, price, nutritional content, and sensory attributes are the most important factors in consumer preferences for packaged beverages. Certification builds trust, safety addresses health concerns, and sensory appeal enhances satisfaction. Price is also significant, emphasizing affordability, while attributes like value and packaging methods hold moderate importance. Nutrition plays a vital role in food acceptance because it directly impacts both consumer perception and decision-making (Kasza *et al.*, 2023). Producer reputation and advertising are least influential. These insights highlight the need for producers to

prioritize certification, safety, sensory appeal, and pricing to meet consumer expectations effectively.

Table 6 - Importance levels of quality attributes

Attributes	**Importance Levels (%)**					
	VI	**I**	**FI**	**LI**	**VLI**	**Total**
Safety	**69.00**	25.33	4.67	0.67	0.33	100
Nutritional content	**39.33**	37.67	17.33	4.67	1.00	100
Sensory	**52.67**	36.00	10.67	0.67	0.00	100
Value	28.33	**45.67**	22.00	3.00	1.00	100
Process	31.67	**35.00**	21.67	9.67	1.33	100
Certification	**74.33**	18.33	6.00	1.33	0.00	100
Packaging method	35.00	**38.00**	23.33	2.67	1.00	100
Price	**55.67**	26.67	13.67	3.67	0.33	100
Producer	24.33	**33.00**	32.00	8.33	2.33	100
Advertising	16.67	29.00	**35.33**	12.00	7.00	100

Note: VI = Very Important; I = Important; FI = Fairly Important; LI = Less Important; VLI = Very Less Important.

Table 7 indicates that consumer preferences span five core areas – sensory attributes, food safety, nutrition, specific added value, and product quality information. Within the sensory domain, taste and texture emerge as top drivers of acceptance; meanwhile, chemical safety and vitamins/minerals rank highest under food safety and nutrition. In terms of added value, consumers prioritize nutritional completeness and size/volume, while product quality information focuses heavily on price and packaging labels. These findings underscore the importance of offering appealing sensory experiences, ensuring safety through transparent labelling, and providing robust nutritional details. Moreover, if packaging cues create expectations that are not met upon consumption, consumer enthusiasm may decline (Gunaratne *et al.*, 2019). As a result, producers must ensure that packaging design and communication consistently reflect the product's genuine characteristics – particularly taste and healthfulness – to fulfil consumer expectations and strengthen purchase intent.

Table 7 - Percentage of selection for sub attributes of sensory, food safety, nutrition, specific added value, and product quality information attribute

Attributes	Sub-Attributes	Total (%)
Sensory	Aroma	8.67
	Appearance and freshness	3.67
	Taste and texture	69.00
	Color	18.66
	Total	100.00
Food safety	Biological safety	29.67
	Chemical safety	68.67
	Physical safety	1.66
	Total	100.00
Nutrition	Calories (carbohydrates)	30.00
	Protein	9.00
	Fats and cholesterol	23.67
	Vitamins and other minerals	37.33
	Total	100.00
Specific added value (expected from product)	Packaging materials and design	21.67
	Product durability	8.00
	Nutritional completeness per package	36.33
	Ease of preparation	7.67
	Size and volume	26.33
	Total	100.00
Product quality information (signals of product quality)	Advertising and other promotions	7.33
	Packaging label	28.00
	Brand name	18.00
	Manufacturer's name	6.00
	Store name (where product is purchased)	1.67
	Price	30.00
	Product reputation	9.00
	Total	100.00

Table 8 underscores the growing significance of process and management sub-attributes in guiding consumer preferences. Consumers place considerable emphasis on origin and organic labels, underscoring a

widespread desire for traceability and eco-friendly production methods. Meanwhile, Halal and BPOM (Indonesia's national food and drug authority) certifications stand out for their strong effect on consumer trust and perceived safety, while HACCP and GMP, though moderately important, reflect the ongoing relevance of standardized quality and safety protocols. Company reputation ranks lower in comparison, suggesting that formal, well-recognized certifications carry greater weight than less-structured assurance signals. These findings highlight the need for producers to invest in robust certification frameworks and transparent operations. By focusing on credible certifications, clear labelling, and sustainable practices, producers can bolster consumer confidence and strengthen their competitive edge (Brukało *et al.*, 2024).

Table 8 - Importance levels of quality attributes

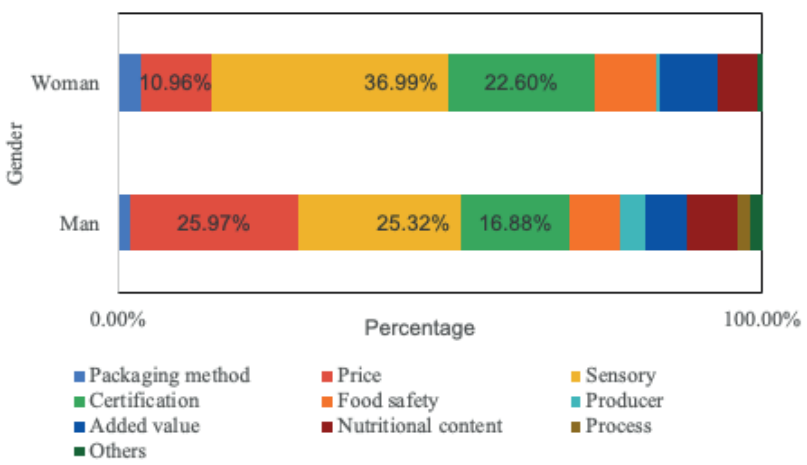
Attributes	**Sub-Attributes**	**Importance Levels**					
		VI	**I**	**FI**	**LI**	**VLI**	**Total**
Process	Origin (%)	**52.33**	33.00	11.67	2.67	0.33	100
	Biotechnology aspect (%)	**34.00**	39.00	22.33	3.67	1.00	100
	Organic product (%)	**50.00**	33.33	14.67	1.67	0.33	100
	Handling (%)	**43.33**	32.67	17.33	5.67	1.00	100
Management	BPOM certification (%)	**73.67**	21.00	4.33	0.67	0.33	100
	Halal certification (%)	**83.33**	11.00	3.67	1.33	0.67	100
	HACCP (%)	**50.67**	35.33	11.33	2.34	0.33	100
	GMP (%)	**51.00**	33.00	12.00	3.33	0.67	100
	Company reputation (%)	32.00	**41.00**	21.00	5.33	0.67	100

Note: VI = Very Important; I = Important; FI = Fairly Important; LI = Less Important; VLI = Very Less Important.

2.3. *Crosstab Analysis of Economic and Socio-Demographic Factors in the Consideration of Quality Attributes*

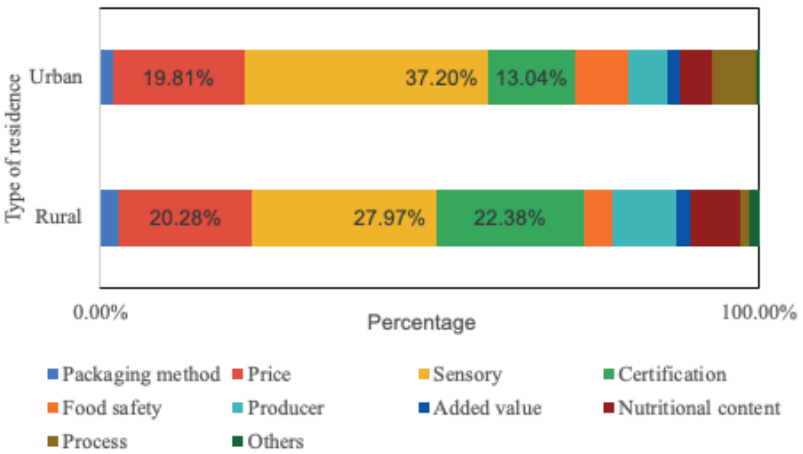
Further analysis focused on the top three prioritized attributes – sensory, certification, and price – through crosstab analysis to assess the role of socio-demographic factors in shaping packaged beverage preferences. As illustrated in Figure 5, sensory appeal was prioritized more by women (36.99%) than men (25.32%), consistent with studies showing that women are more attuned to sensory and emotional dimensions of consumption (Nagina *et al.*, 2024). Similarly, certification was more frequently cited by women (22.60%) than men (16.88%), indicating that female consumers may place greater emphasis on safety, transparency, and quality assurance when selecting beverages. Gender differences affect how health-related information impacts beverage acceptance. For instance, males and females may respond differently to health benefit claims, which can influence their willingness to try new beverages (Collins & Lalor, 2024; Thompson *et al.*, 2024). In contrast, price considerations were more prevalent among male respondents (25.97% vs. 10.96%), suggesting that men tend to prioritize economic value in purchase decisions. These findings reinforce existing evidence that gender not only influences how quality attributes are perceived but also reflects broader behavioral tendencies – where women are more attentive to certification and health signaling, while men focus more on functionality and affordability.

Figure 5 - Crosstab analysis of the relationship between gender and the selection of general attributes



Residence, income, and education levels significantly shape consumer preferences for packaged beverages. Figure 6 shows that urban consumers tend to prioritize sensory attributes (37.20%), followed by price (19.81%) and certification (13.04%), reflecting an emphasis on product appeal and perceived quality assurance. This trend aligns with findings from Chile and the U.S., where urban populations are more frequently exposed to policy interventions – such as food labelling regulations and sugar taxes – that shape their purchasing behaviour (Knox & Jones-Smith, 2025; Taillie *et al.*, 2020). In contrast, rural consumers exhibit a more evenly distributed preference, notably placing comparable emphasis on sensory (27.97%) and certification (22.38%). This may reflect a greater reliance on official endorsements and certifications as trusted indicators of product safety and quality (Isharyadi & Kristiningrum, 2021), especially in areas with limited access to brand diversity or lower exposure to advertising and in-store marketing. Thus, certification plays a compensatory role in helping rural consumers evaluate product credibility in the absence of other quality signals.

Figure 6 - Crosstab analysis of the relationship between residence and the selection of general attributes



Education level plays a key role in shaping consumer preferences for packaged beverage attributes. Consumers with higher education place greater emphasis on sensory attributes (33%), reflecting a focus on taste, aroma, and overall consumption experience. In contrast, those with lower education levels prioritize price (25%) and certification (20%), highlighting the importance

of affordability and trust in product safety and quality. These findings suggest that marketing and consumer education strategies should be tailored to different educational backgrounds to effectively influence purchasing decisions (Andreea & Paula, 2019).

Figure 7 - Crosstab analysis of the relationship between education and the selection of general attributes

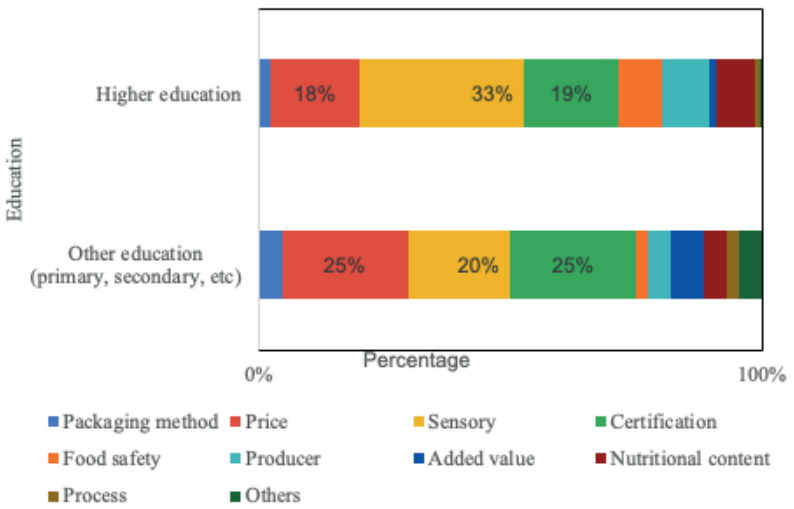
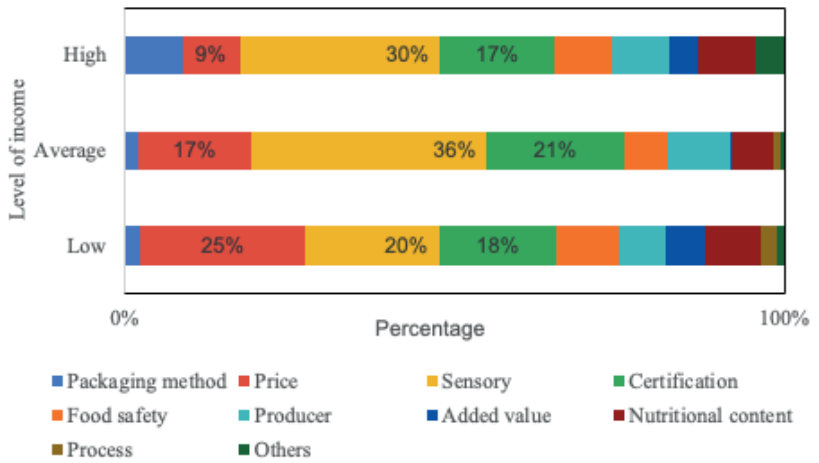


Figure 8 reveals notable differences in attribute prioritization across income levels. High-income consumers are primarily driven by sensory attributes (30%), followed by certification (17%), while price (9%) becomes the least influential. This implies a shift towards quality, safety, and premium perception as income increases. Average-income consumers prioritize sensory attributes (36%) the most, suggesting a desire for enjoyable consumption experiences. Certification (15%) and price (17%) are also relevant, indicating a balanced consideration between enjoyment, assurance, and value. Low-income consumers show the strongest preference for price (25%), indicating affordability as their primary concern. Sensory (20%) and certification (14%) follow, reflecting interest in taste and product assurance despite budget constraints. These findings align with prior research showing that lower-income households are more sensitive to price and tend to reduce consumption of taxed or premium beverages more than higher-income groups (Eyles *et al.*, 2024; Knox & Jones-Smith, 2025).

Figure 8 - Crosstab analysis of the relationship between income and the selection of general attributes



2.4. *Factor analysis of quality attributes*

Consumers have varying perceptions when evaluating quality attributes in packaged beverage products, particularly regarding the importance of general quality attributes. These differences may arise from external consumer factors such as economic and socio-demographic influences. The patterns formed from respondents' evaluations can be used to identify the position or role of each quality attribute. Additionally, these patterns can reveal relationships between quality attributes, leading to the formation of new groupings of quality attributes. The newly formed quality attribute groups can reflect perceptions of quality within specific consumer segments. Three new factors (groups) of quality attributes were identified through factor analysis. The grouping was based on the highest factor loadings among the three factors. Factor loadings indicate the role of each variable within a factor, where higher factor loadings signify a greater contribution of the variable to that factor (Sappaile *et al.*, 2023).

Based on Table 9, the factor analysis of quality attributes reveals that the first factor comprises safety, nutrition, process, and certification. While certification is an extrinsic attribute, its inclusion among intrinsic factors is justified by its role as an indicator of quality assurance, encompassing safety, nutrition, and processing in packaged beverages. This grouping is referred to as the **intrinsic credence factor (factor 1)**, characterized by attributes that are not directly observable but can be evaluated through certification. Recent

Table 9 - Results of factor analysis on quality attributes

Attributes	Factor Loadings		
	1	2	3
Safety	.756*	–0.055	0.099
Nutrition	.674*	0.177	0.000
Process	.659*	0.325	0.000
Certification	.654*	–0.018	0.19
Producer	–0.001	.818**	0.106
Advertising	0.099	.796**	0.16
Packaging method	0.373	.493**	0.248
Price	–0.008	0.012	.775***
Sensory	0.106	0.191	.706***
Value	0.241	0.350	.575***

Note: * Factor 1; ** Factor 2; *** Factor 3.

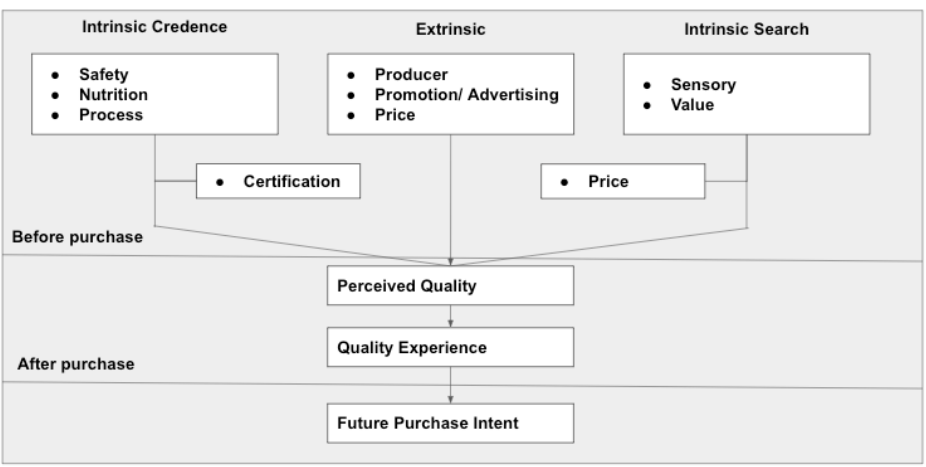
studies further emphasize the importance of intrinsic attributes in shaping consumer preferences. Credence attributes, such as food safety and eco-friendliness, have been shown to positively influence attitudes toward organic food (Huo *et al.*, 2023), while consumers exhibit heightened sensitivity to intrinsic qualities, particularly in organic or locally sourced products, driven by health and environmental sustainability motivations (Varaldo *et al.*, 2022). The significance of these attributes is also reflected in market behaviour, where the inherent uncertainty of credence goods often compels consumers to rely on suppliers' expertise, highlighting the importance of trust and perceived quality in purchasing decisions (Karunadasa *et al.*, 2023).

The second factor includes attributes such as producer, advertisement, and packaging, which are categorized as **extrinsic factor (factor 2)** in packaged beverages. Among these, the producer attribute is particularly impactful due to its direct involvement in the production process, which ultimately shapes the quality of the product. Research indicates that sophisticated marketing techniques, including health claims and appealing packaging designs, can enhance consumer perceptions and preferences, thereby increasing the desirability of products, especially ultra-processed foods (Baker *et al.*, 2020). These marketing strategies are aimed at improving the immediate appeal of the product and establishing a brand identity that resonates with consumers, which is crucial in a competitive market (Mpuon *et al.*, 2023). The role of advertisement in promoting packaged beverages is substantial. Studies

have shown that advertisements significantly affect consumer behaviour, particularly among children and adolescents, who are often targeted through various media channels (Backholer *et al*., 2021; Powell *et al*., 2024). The effectiveness of these advertisements is amplified when they are strategically placed in environments frequented by the target demographic, such as schools and urban neighborhoods (Amevinya *et al*., 2022).

The third factor, known as the **intrinsic search factor (factor 3)**, encompasses price, sensory attributes, and perceived value. This factor integrates intrinsic qualities such as sensory appeal and value with the extrinsic attribute of price. Price often acts as a dependent variable, adjusting in response to the quality of sensory and value attributes. Research highlights that sensory attributes, including aroma and flavour, play a pivotal role in enhancing a product's perceived value and can justify higher pricing, demonstrating a strong correlation between sensory appeal and pricing strategies. For example, consumers frequently prioritize sensory qualities when making food choices, while price remains a critical factor influencing their decisions (Barahona *et al*., 2020; Souza *et al*., 2020). This relationship underscores the essential role of sensory attributes in shaping perceived value and determining pricing strategies. Moreover, the intrinsic search factor aligns with findings that consumers can anticipate the quality of intrinsic attributes before purchase and confirm their evaluation after consumption. Sensory attributes not only influence consumer preferences but also directly affect their willingness to pay, reinforcing the value of these qualities in driving purchasing decisions (Barahona *et al*., 2020).

Figure 9 - Diagram of the packaged beverage quality acceptance model



Based on Figure 9, the quality acceptance model for packaged beverages, consumers' perceptions of packaged beverage products are shaped by **a combination of intrinsic credence attributes, intrinsic search attributes, and extrinsic attributes**, which together influence the overall evaluation of product quality. Intrinsic attributes, such as taste and nutritional value, are directly linked to the fundamental properties of the product and serve as key indicators of its quality. These attributes inherently reflect the product's characteristics, making them critical in assessing its functionality and acceptability. On the other hand, extrinsic attributes – such as packaging design, branding, and labelling – act as supplementary factors that enhance the perceived quality of the product. Although they do not represent the product's inherent properties, these attributes provide additional quality cues that become especially important when intrinsic attributes are already optimized. For example, research highlights that clear and aesthetically designed packaging and labels not only improve perceptions of quality but also instil confidence and clarity regarding the product's attributes (Nimoh *et al*., 2024).

The interaction between intrinsic and extrinsic attributes plays a significant role in quality evaluation. While intrinsic attributes often serve as the primary criteria due to their direct influence on product functionality, extrinsic attributes provide complementary support by shaping pre-consumption quality perceptions, particularly in competitive markets where differentiation is key (Arenas de Moreno *et al*., 2020; Yang *et al*., 2021). While the model was developed in the context of packaged beverages, its conceptual framework may be extended to other fast-moving consumer goods (FMCG) categories such as snack foods, dairy products, and ready-to-eat meals. In these sectors, consumers also evaluate a combination of intrinsic and extrinsic attributes when making purchasing decisions. Similarly, different consumer demographics – such as older adults or caregivers shopping for children – may weigh these attributes differently, emphasizing factors like safety, labelling clarity, or ease of preparation. This highlights the potential adaptability and broader relevance of the proposed model. Post-purchase, consumers integrate these evaluations by comparing the product's actual quality with their expectations, a process that results in the formation of "experienced quality". These post-consumption reflections form a critical feedback loop that influences future purchase intentions, loyalty, and brand advocacy. If the experienced quality aligns with or exceeds expectations, consumers are more likely to repurchase and recommend the product (Ebrahim *et al*., 2024). On the other hand, unmet expectations may lead to negative word-of-mouth and diminished trust. Acknowledging this feedback mechanism reinforces the importance of delivering consistent product performance to build long-term consumer relationships.

This comprehensive evaluation enables consumers to develop a more holistic understanding of the product's overall quality and its ability to meet their expectations.

The findings of this study provide valuable insights for both producers and policymakers, guiding them in meeting consumer expectations and promoting healthier beverage choices. For producers, the results suggest a clear shift toward health-oriented products, particularly those with low sugar content and high nutritional value. As Generation Z consumers place significant importance on attributes such as food safety, nutritional content, and sensory appeal, producers should focus on reformulating packaged beverages to align with these preferences. This could involve reducing the use of artificial sweeteners, adding beneficial nutrients like vitamins and minerals, and incorporating functional ingredients such as probiotics or prebiotics. In addition to health considerations, the study emphasizes the significance of certifications, such as Halal or quality assurance labels, in building consumer trust. Producers should prioritize obtaining and prominently displaying these certifications to reassure consumers of product quality. Furthermore, sensory attributes like taste, aroma, and texture continue to play a crucial role in consumer preferences. Producers should invest in improving these sensory characteristics through better ingredient sourcing and innovation in processing methods. Price remains a critical factor as well, with consumers perceiving higher-priced beverages as higher quality, making it important for producers to strike the right balance between quality and affordability.

For policymakers, the study underscores the importance of regulatory measures such as front-of-pack nutrition labelling and fiscal policies like sugary beverage taxes. By implementing clear, easy-to-understand labelling systems, policymakers can help guide consumers towards healthier choices, particularly in the context of reducing sugar intake. Additionally, the study highlights the effectiveness of policies that promote transparency, such as agri-food traceability systems, which can further enhance consumer confidence in the safety and quality of packaged beverages. Policymakers should continue to support initiatives that encourage producers to reformulate their products in line with health standards and ensure that consumers are equipped with the necessary information to make informed purchasing decisions. By fostering a regulatory environment that prioritizes health and sustainability, policymakers can contribute to the long-term improvement of public health outcomes while simultaneously supporting industry innovation.

Conclusions

This study explored Generation Z's preferences for packaged beverage quality attributes, identifying sensory appeal, certification, and price as

the primary drivers of consumer choice. Factor analysis revealed three key dimensions that shape Gen Z's perception of quality: intrinsic credence (e.g., safety, nutrition, certification), extrinsic (e.g., branding, advertising, packaging), and intrinsic search (e.g., sensory appeal, price, perceived value). These findings demonstrate how Gen Z consumers evaluate products through a combination of health-consciousness, trust indicators, and practical value assessments.

The study contributes to the literature by applying Caswell's quality framework in a multidimensional model tailored to Generation Z's values and behaviors. The findings have several practical implications. For instance, producers should enhance sensory attributes by reducing artificial additives and using natural ingredients. Certifications such as Halal or certificate from national food and drug authority should be clearly displayed on front-of-pack labels to foster consumer trust. Since price also plays a key role, offering smaller, affordable packaging sizes may help attract price-sensitive consumers without compromising perceived quality.

For policymakers, the findings reinforce the value of front-of-pack nutrition labeling systems that simplify health information for consumers. Additionally, incentives or tax policies that support the production of low-sugar or functional beverages could help drive healthier market trends. Public health campaigns that leverage social media and influencer channels – platforms familiar to Gen Z – may also prove effective in promoting healthier consumption.

Nevertheless, the study has limitations. The use of non-probability purposive sampling and self-reported online data may limit generalizability. Future research should expand demographic and geographic diversity and consider post-purchase experiences to better understand long-term consumer behavior and satisfaction.

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Feeding the gap: A comprehensive bibliometric review of food bank research

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Abstract

This study presents a comprehensive bibliometric analysis of the food bank literature, highlighting the role of food banks in addressing the global challenges of food insecurity and waste. Food banks operate at the nexus of waste reduction and hunger alleviation, collecting excess food and distributing it through a network of charities to communities in need. This study traces the scholarly evolution of food banks, highlighting key trends, contributors, and thematic clusters from 1997 to 2022. Bibliometric mapping tools are used to examine the dynamic research landscape and identify influential authors, journals, and the geographical spread of contributions. The analysis reveals a significant increase in research output post-2015, correlating with the global agenda towards Sustainable Development Goals. The United States and Canada have emerged as leading contributors, with the research network indicating robust international collaborations. Thematic analyses through keyword co-occurrence, co-citation, and bibliographic coupling uncover the multidisciplinary nature of food bank studies, encompassing public health, social policy, and environmental sustainability. Key findings from co-citation and bibliographic coupling analyses indicate a shift towards a holistic understanding of food banks' roles within societal and policy frameworks, emphasizing health outcomes, operational strategies for managing food waste, and the socio-political impacts of austerity measures. This paper underscores

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the importance of continued interdisciplinary research and innovative policy formulations to ensure that food banks effectively address the complex dynamics of food insecurity. Despite its limitations, this study offers a robust foundation for future exploration in this field, providing support for broader inclusivity and diversity in research.

Introduction

In an era where food insecurity and waste present paradoxical global challenges, food banks emerge as critical mediators in the pursuit of sustainable solutions (Household Food Insecurity and Hunger among Families Using Food Banks – ProQuest, n.d.). As non-profit entities, food banks operate at the intersection of waste reduction and hunger alleviation, embodying a dual-purpose mission that is as humanitarian as it is ecological (Thyberg *et al*., 2015) At their operational core, food banks are more than mere conduits of food redistribution. They collect excess food from different sources – ranging from farms, manufacturers, distributors, retail stores, consumers, and other entities – and ensure its safe and efficient distribution through a network of smaller charities and community agencies (González-Torre & Coque, n.d.). These partner organisations, in turn, distribute this nourishment to individuals and communities grappling with food scarcity (Starkey, Kuhnlein, Phd, *et al*., 1998).

This process varies across national contexts, reflecting the complexities of food insecurity and distribution logistics. In addition to their redistributive function, food banks often serve as direct service providers, supplying essential grocery items directly to beneficiaries (Campbell *et al*., 2013; Kicinski, 2012).

In the United Kingdom, the trajectory of food bank usage has dramatically increased. After 61,000 emergency food parcels were supplied in 2010/11, the number soared to 1.9 million by 2019/2020 (Bramley, 2021). The advent of the COVID-19 pandemic marked a stark increase in dependency on these services, with approximately 700,000 households, accounting for approximately 2.5% of all households in the UK, resorting to food banks before the pandemic struck.

Across Europe, 341 food banks have been actively engaged in fostering a circular food economy, emblematic of a unique blend of social responsibility and environmental conservation (FEBA, 2021). Despite a historical decrease in hunger rates, in 2021, an estimated 21% of the EU population, or approximately 95.4 million people, were still at risk of poverty or social exclusion, highlighting the persistent challenge of hunger on the continent (Davis *et al*., 2014).

The concept of food banks has not undergone recent development. The first food bank was established in Arizona, USA, in 1966, with Europe following suit in 1984, inaugurating its first in Paris (Riches, 2002). In nations such as the USA and Canada, the role of food banks is particularly relevant (Dowler, 2001). The COVID-19 pandemic has intensified food insecurity and disrupted further food supply chains, elevating the importance of food banks in crisis response. In fact, only in 2020, according to FEBA members, 860,000 tonnes of food (+12% compared to pre-COVID-19 levels) were recovered, collected, sorted, stored, and redistributed to support 48,126 charitable organisations helping 12.8 million people in need (+34.7% increase compared to pre-COVID-19 levels). Moreover, global challenges such as the conflict in Ukraine have further aggravated the food crisis, driving up the costs of food, fuel, and fertilizers (Juneja *et al*., 2023).

The United Nations Food Price Index revealed that food prices in 2022 reached record highs, increasing nearly 13% since the conflict began. The confluence of climate change, civil unrest, and projected population growth to 9.7 billion by 2050 pose daunting challenges to food security and the sustainability of global agricultural systems (The Future of Food and Agriculture and Challenges, n.d.). These developments, alongside the Sustainable Development Goals (SDGs), highlight the imperative to reimagine food banks not only as emergency stopgaps but also as foundational pillars in a sustainable food ecosystem.

Since 2007, scientific inquiry into food banks has experienced a notable surge, signifying increasing interest among researchers in this domain. However, despite their critical role and recognition, the academic exploration of food banks has been somewhat fragmented, lacking a comprehensive, holistic analysis. While previous studies have examined food banks from disciplinary perspectives such as public health, social policy, and environmental sustainability, there has been little effort to consolidate these discussions into a unified framework. This study addresses this gap by providing a systematic bibliometric analysis that traces the trajectory of food bank research, mapping key contributors, dominant themes, and evolving research priorities.

This paper aims to fill this gap by providing a detailed bibliometric analysis of the scientific literature on food banks. We investigate the evolution of scholarly contributions in this field by examining publication and citation trends and identifying the most influential authors, journals, and contributing nations. Using bibliometric mapping tools, we delve into the dynamic emergence and progression of research themes, offering insights into the multifaceted challenges and potential avenues for future development in food banking. By identifying thematic clusters and research frontiers, our study offers critical insights into the shifting discourse surrounding food banks,

revealing how they have evolved from emergency food assistance programs to integral components of broader socio-political and environmental discussions.

Through this analysis, we seek to investigate the significance of food banks in the contemporary context and offer a robust academic foundation for future research and policy development in this field.

The paper is organised as follows. The methodology section details the analytical approach and techniques employed in the bibliometric analysis, offering insights into the data collection and analysis processes used to investigate the literature of the last 25 years. The results section presents the study's key findings, delving into the emerging themes and trends identified in the research landscape. This section also provide a map of the most relevant papers thanks to a cluster approach, based on co-citation analysis and bibliographic coupling.

The last section encompasses synthesizes the insights from the analysis, discussing the socio-political dimensions of food banks and their evolution, with specific regards to the practical implications for policymakers and practitioners, summarizing the overall contributions of the paper to the existing body of literature, describing some limitations of the study.

1. Materials and Methods

Bibliometric analysis is a set of methodologies that employs statistical tools to systematically chart a specific scientific field's development and intellectual landscape. Extensively used for dissecting vast volumes of scholarly literature, it employs a blend of quantitative and qualitative techniques to measure and monitor scientific outputs and to visualize the complex interrelationships within the academic literature (Porter *et al.*, 2002) (Donthu *et al.*, 2020, 2021a; Verma & Gustafsson, 2020).

This type of analysis has recently gained popularity due to the advancement, availability, and accessibility of bibliometric software and scientific databases such as Scopus and Web of Science (Donthu *et al.*, 2021a). This study is based on data retrieved from the Web of Science (WoS), a comprehensive database of scholarly literature focusing exclusively on articles across various disciplines. A systematic search was conducted within the WoS database to collate all pertinent articles on the subject. In July 2022, the search query used to collect the data were "food bank*" across titles, abstracts, and keywords to ensure a thorough and relevant collection of articles. Specific filters to refine the dataset were applied to collect exclusively articles published in scientific journals between 1997 and 2021 and written only in English. To further ensure relevance and precision, each title and abstract was manually reviewed, eliminating any articles that

did not directly pertain to the topic of food banks. This selection process led to the identification of 563 papers written by 1,573 distinct authors.

Within bibliometric methodologies, two main groups of tools can be identified: performance analysis and science mapping. Performance analysis evaluates the impact of research outputs by examining metrics such as citation counts, h-indexes, and journal impact factors to identify influential authors, institutions, and countries within the food bank literature. This analysis highlights the contributions that have garnered significant attention and shaped the discourse within the field. Science mapping, on the other hand, visualizes the relationships and thematic clusters within a specific scientific domain. Specifically, keyword co-occurrence, co-citation analysis and bibliographic coupling were carried out in this research.

Keywords co-occurrence analysis examines the frequency and patterns of keyword usage across the literature, identifying terms that frequently appear together within the same documents or during certain periods. By mapping these co-occurrences, we can visualize the conceptual structure and thematic areas of the field, highlighting the main topics of interest and their interrelations. Keywords co-occurrence analysis is particularly valuable in revealing emerging research trends and the evolving vocabulary of a scientific domain; it allows researchers to discern the core themes that define the discourse and how these themes are interconnected, providing insights into the field's focus areas and potential directions for future research. This analysis complements co-citation and bibliographic coupling by offering a different lens through which to view the intellectual landscape, focusing on the language and terminology that shape the scholarly conversation around food banks.

Co-citation analysis was proposed by Small in 1973 (Marshakova, 1973; Small, 1973; Small & Crane, 1979; Small & Griffith, 1974) to capture literature contributions, decipher and map cumulative scientific knowledge and evaluate related research topics (Donthu *et al.*, 2021b). Two documents are deemed co-cited when they are present in the reference list of a third document; the intensity of their correlation is directly proportional to the number of papers in which they are concurrently cited (Ruggeri *et al.*, 2019). Cocitation analysis investigates the network formed by references that are cited together in multiple documents, offering insights into intellectual structure and dynamics (Braam *et al.*, 1991). This method divides a corpus of literature into clusters of articles frequently cited together, revealing patterns and connections that might not be immediately apparent (Cobo *et al.*, 2011). This methodology not only identifies the foundational papers within a field but also sheds light on how ideas and research have evolved, offering a comprehensive understanding of the field's intellectual lineage and current frontiers. Moreover, this analysis was employed to trace the connections

among intellectual works and effectively map the evolutionary structure of scientific disciplines, uncovering the interrelationships and dynamic evolution of scholarly contributions within diverse fields of scientific inquiry.

Finally, bibliographic coupling explores connections between articles through their shared references, suggesting a relationship between papers that cite common sources (Glänzel & Czerwon, 1996; Jarneving, 2007; Vladutz & Cook, 1984). Unlike cocitation, which looks backwards at the field's intellectual heritage, bibliographic coupling is forward-looking, revealing current research trends and the emergence of new themes by analysing the interconnectedness of recent publications. In bibliographic coupling, the formation of clusters is based on the references that articles have in common, allowing for the identification of thematic linkages and intellectual trajectories within a research domain (Donthu *et al.*, 2021).

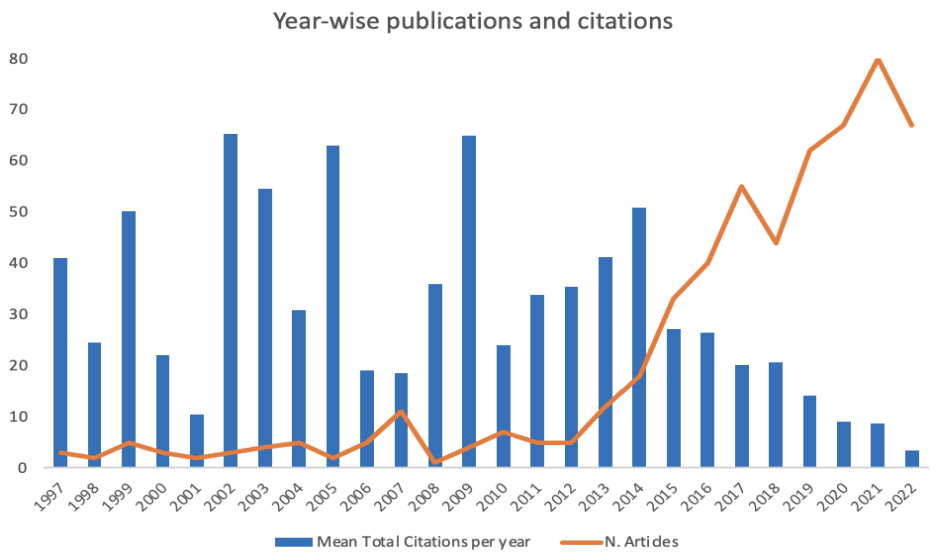
The application of a bibliometric approach to the analysis of food bank literature contributes to a more detailed understanding of this topic, as it not only highlights the growth of food bank research but also reveals significant shifts in thematic priorities. In particular, the descriptive data in Figures 1, 2, 3, and 4 illustrate the evolution of publications on food banks, highlighting the role of the most productive authors and journals, as well as the level of collaboration between countries. Furthermore, the timeline view of keyword co-occurrence analysis, shown in Figure 5, captures the changes in the most relevant topics over the considered period. Finally, the combined use of co-citation and bibliographic coupling provides a comprehensive view of the literature, encompassing both foundational studies and the most recent contributions. Bibliometric analysis provides a powerful means of systematically evaluating the evolution of scientific discourse. Unlike traditional literature reviews, which may be subject to selection biases, bibliometric tools enable a quantitative assessment of research trends, scientific networks, and keywords' evolution. This approach allows us to visualize the intellectual structure of food bank research and identify knowledge gaps that may not be immediately apparent in qualitative reviews. However, the reliance on citation frequency is one of the most relevant limitation of bibliometric methods, because they could overestimate the importance of mainstream topics and misrepresent the niche or emerging themes. A careful reading of the papers and an in-depth knowledge of the literature on food banks has allowed us to mitigate this endogenous limitation of the method.

2. Results and Discussion

Figure 1 displays the total number of publications and the average number of citations per year between 1997 and 2022, showing a right-skewed

distribution in the number of articles published, indicative of continuous growth in research output. The emergence of food bank studies occurred in the early 2000s, but it gained significant attention as a research topic only since 2016, with an average of 49.5 yearly articles published in the last decade. The growing interest in food banking occurred concurrently with the release of the Sustainable Development Goals (SDGs) in 2015, which placed food banking as a practical food aid tool to achieve SDG 2 and SDG 12, namely, "No Hunger" and "Responsible consumption and production". The number of citations per year varies significantly during the entire period; not surprisingly, newer publications received fewer citations on average than older publications.

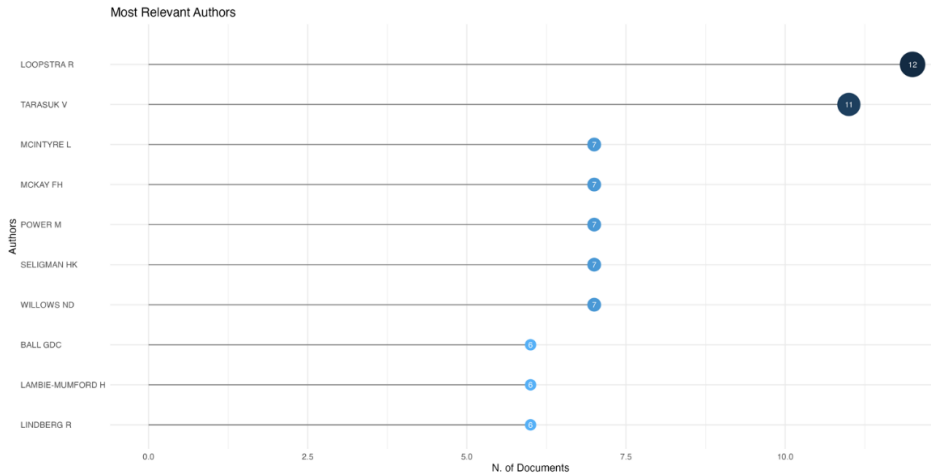
Figure 1 - Yearwise publication trend of papers related to food banks during 1997-2022



2.1. *Author and journal analysis*

In the exploration of key contributors within food bank-related research, we identified a total of 1,573 authors who have made significant contributions to this field. The most productive authors in terms of the number of publications are presented in Figure 2. Among these, two authors stand out for their prolific work. Loopstra is the most productive author, with a total of 12 articles, primarily centred on the interplay between food banks and food

Figure 2 - The 14 most productive authors from 1997 to 2022



insecurity in high-income countries, as well as examining the demographics of beneficiaries reliant on emergency food assistance. Tarasuk, who has authored 11 articles closely, focused her research on the integration and function of food banks within the Canadian welfare system.

Figure 3 - The ten most prolific journals during 1997-2022

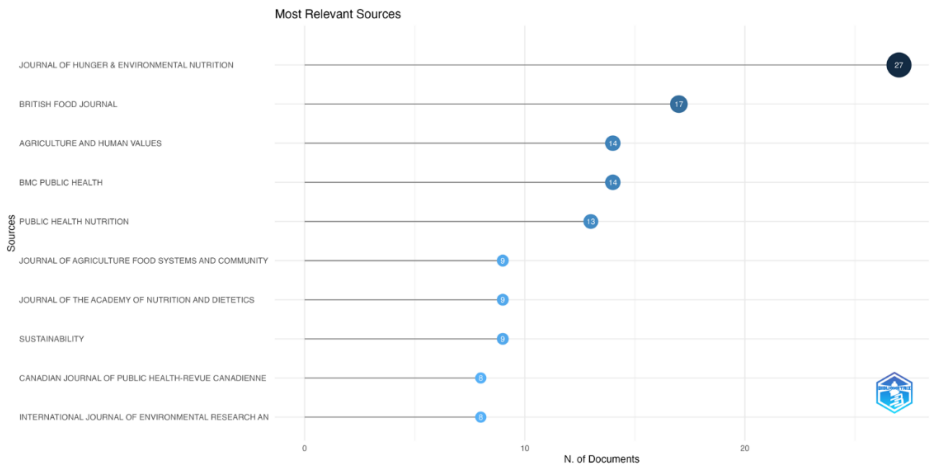
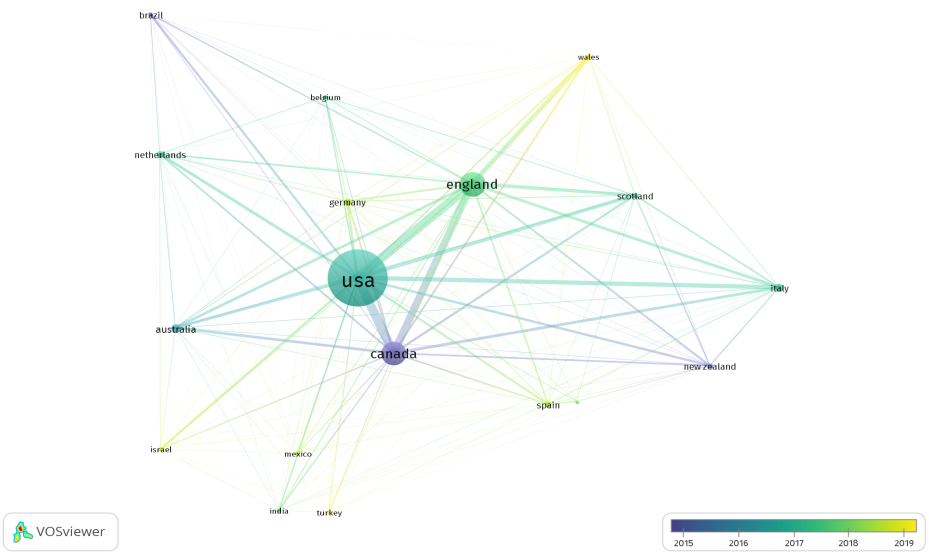


Figure 3 offers a visual summary of the most relevant sources identified in our bibliometric analysis of food bank literature. The Journal of Hunger & Environmental Nutrition is the most prolific source, with 27 documents, indicating an important role in disseminating research on food banks and their intersection with environmental considerations. The British Food Journal and Agriculture and Human Values follow with 17 documents each, underscoring their significant contributions to the discourse on food banks, particularly in the context of food systems and societal values. With 14 and 13 documents, BMC Public Health, and Public Health Nutrition, respectively, reflect the growing recognition of food banks in the public health arena. All the other journals in Figure 3 contribute to a substantial body of research, highlighting the interdisciplinary nature of food bank studies and the diverse influence of these journals in shaping the dialogue around food security and the sustainability of food systems considering recent global crises.

2.2. *Country analysis*

Figure 4 - Cooperation network of the 18 most productive countries



The network represented in Figure 4 provides a view of international contributions and collaboration in food bank research. The size of the nodes, representing different countries, is proportional to the number of publications

from each nation, with the USA and Canada emerging as the most significant contributors in the field. This prominence is indicative of the extensive research activity related to food banks within these countries, reflecting their long-standing engagement with food insecurity and waste. The colour gradient of the nodes, ranging from blue to yellow, corresponds to the average year of publication, ranging from 2015 to 2019.

Lines connecting the nodes signify collaborative efforts between countries, and the thickness of these lines reflects the strength of the research ties. Notably, the USA is central to the network, demonstrating robust collaborative links with various countries and emphasizing its pivotal role in global food bank research. England, Canada, Germany, and Australia also display notable contributions and connections, highlighting their active participation in international research collaborations.

Developed countries, represented by larger nodes such as the USA, Canada, and England, dominate the network, indicating a greater volume of research output and a more extended history of established food bank systems. However, these nations are usually at the forefront of scholarly contributions for most research topics, reflecting their advanced research infrastructures. Conversely, smaller nodes from developing countries, such as Brazil, India, and Mexico, suggest that while developed countries may provide a foundation for research, there is an invaluable exchange with developing countries that can offer novel insights and adaptations suited to diverse global contexts.

Figure 5 - Timeline view of keyword co-occurrence analysis

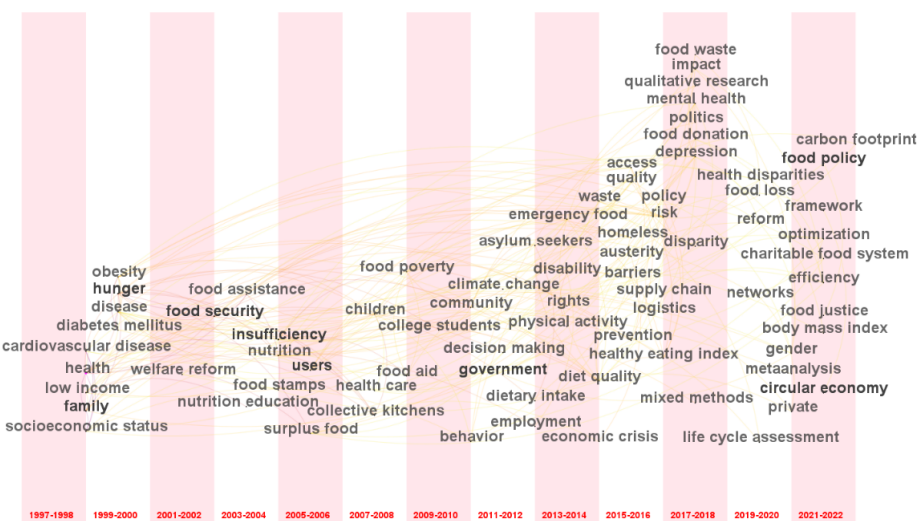


Figure 5 depicts the evolution of keywords in food bank research from 1997 to 2022. In the late 1990s, key themes emerged in the nascent literature on food banks, despite a modest number of publications. Initially, the literature was focused on fundamental issues of food security, health, and nutrition, with terms such as "hunger", "obesity", "food insecurity", "families", and "low income", representing the main keywords associated with food banks. This emphasis signals an early understanding of the links between food banks and broader public health and socioeconomic issues. These terms also reflect the initial focus on food banks as emergency measures to provide safety nets for vulnerable populations, particularly during economic downturns. Additionally, terms such as 'disease' and 'diabetes mellitus' highlight the link between food banks and health outcomes. Obesity and type II diabetes, which are conditions often associated with poor nutrition, point to the significance of food quality provided by food banks.

As the discourse matured in the early 2000s, terms such as "nutritional education", "insufficiency", and "nutrition" became prevalent, marking a significant transition in the perception of food banks from solely charity-based entities to integral components of broader social welfare systems. Additionally, the conversation expanded to encompass terms such as "welfare reform", "food stamps" and "food assistance", reflecting a growing recognition of the institutional and policy frameworks surrounding food banks. The appearance of 'surplus food' during this period also underscores an increasing concern with managing food resources.

From 2009 to 2016, the literature expanded to reflect the complexities of food bank operations against the backdrop of the financial crisis and heightened climate change awareness. Research during these years started to address the complexity of food bank operations and their role in public health and social welfare, as evidenced by the discussion around "diet quality" and "healthy eating index", reflecting concerns about the nutritional value of food distributed to those in need. The term "food poverty" becomes more prominent, emphasizing the socioeconomic dimensions of food insecurity. This period also saw a rise in terms such as "austerity", signaling the impact of economic policies on vulnerable populations and the increased reliance on food banks as safety nets. "Emergency food" emerges as a critical concept, highlighting the discussion around the shift in the perception of food banks as part of an essential response to immediate needs in times of crisis. This aligns with the appearance of "asylum seekers" and "homelessness" in the discourse, pointing to the broadening scope of food bank users due to global migration and housing instability. The period also notes an increased focus on "climate change", indicative of a growing consciousness about environmental impacts on food security. The term "supply chain" suggests a

deeper exploration into the logistics of food distribution, including how food banks fit into the larger picture of food systems. Moreover, the expansion of the type of beneficiaries at the centre of food bank studies can be noted, from low-income families to families including "college students" and "communities".

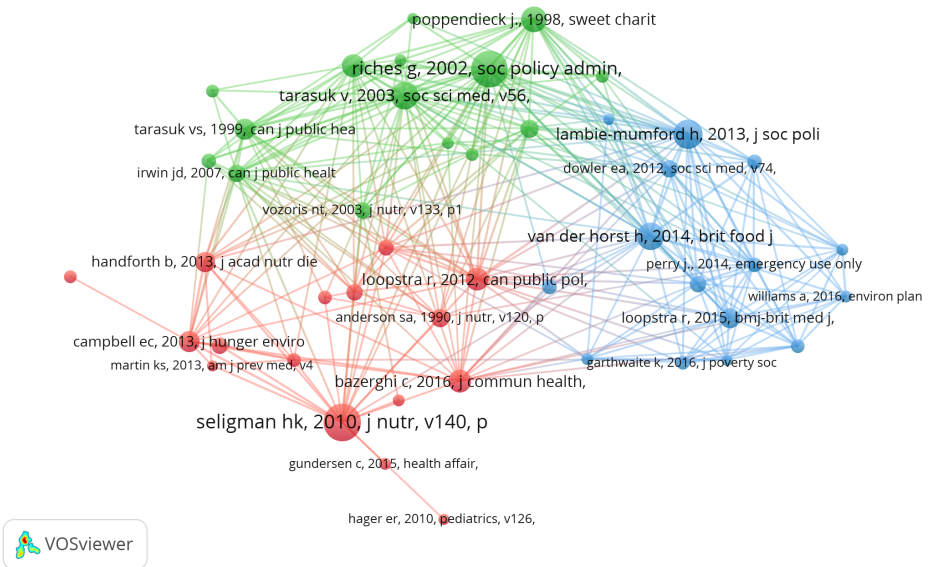
The period from 2017 to 2022 shows an evolving and increasingly complex dialogue within the food bank research community, mirroring the pressing global challenges of this era. During these years, we observed a significant presence of terms such as "food waste" and "impact", reflecting a heightened focus on the environmental implications of food redistribution and the role of food banks in sustainable food systems. The terms "mental health" and "politics" suggest a more profound recognition of the psychological effects of food insecurity and the influence of political structures on the efficacy of food banks. This is complemented by the inclusion of "health disparities" and "depression", indicating an understanding of the broader health implications of hunger and poverty. The dialogue around "food policy", "carbon footprint", "life cycle assessment", and "circular economy" reveals an interdisciplinary approach to food bank research, integrating perspectives from public health, environmental science, and economic theory and highlighting the necessity for comprehensive policy frameworks to address the sustainability and efficiency of food banks in the face of global food system challenges. The increase in keywords such as "meta-analysis" and "mixed methods" indicates a methodological expansion, revealing a trend toward more comprehensive data analysis in food bank studies. The data presented in Figure 5 underscore the dynamic nature of food banks and their evolving roles in society. From their early days as emergency safety nets to their current positions as agents of change in public health and social reform, food banks have adapted to the shifting needs of communities. This evolution highlights the importance of continued research and policy development in ensuring that food banks effectively address the complex challenges of food insecurity in contemporary society.

2.3. *Co-citation analysis*

Figure 6 shows the co-citation network of publications in food bank research, with the threshold of the minimum number of cited references set at 20. Each node in this network represents a scholarly work, with the node's size corresponding to the frequency of co-citation by other works within our dataset. Lines connecting the nodes – each representing co-citation relationships – illustrate the scholarly dialogue between these publications. The proximity of nodes suggests thematic similarities and shared discourse,

with clusters of closely positioned nodes indicating a strong interconnection in research focus or methodology. Distinct colour groupings represent unique clusters identified by VOSviewer, each signifying a thematic concentration or a community of research with a common focus. The network contains 51 articles divided into three clusters, including 21 articles in the first cluster, 17 in the second and 11 in the last.

Figure 6 - Cocitation network analysis using VoSviewer



Cluster 1 – RED-The tight link between food banks and food insecurity

The documents in the first cluster delineate the interplay between food insecurity and food banks, emphasizing their pivotal role in emergency food provision. It includes foundational works, notably by Loopstra and Tarasuk, that have laid the theoretical groundwork for understanding food banks. Bazerghi, McKay, and Dunn's comprehensive review is particularly significant for highlighting the efficacy of food banks in alleviating food insecurity (Bazerghi *et al.*, 2016). Despite their efficiency, the review also identifies persistent challenges such as increasing client numbers, supply-demand mismatches, and resource mismanagement that impede food banks' capacity to meet all beneficiaries' needs comprehensively. The cluster further explored the multifaceted nature of food banks and food insecurity. Loopstra and Tarasuk (Loopstra & Tarasuk, 2012) delve into the barriers faced by

individuals accessing food banks in Canada. Concurrently, Robaina and Martin analysed the interconnections between food insecurity, dietary inadequacies, and obesity among users of these banks (Robaina & Martin, 2013). Extending the scope, Seligman (Seligman *et al.*, 2010) investigated chronic diseases in low-income demographics, while Simmet (Simmet *et al.*, 2017) and Stuff (Stuff *et al.*, 2004) assessed the nutritional quality of food distributed by banks and the health status of food-insecure households, respectively. In addition, Kirkpatrick and Tarasuk (Kirkpatrick & Tarasuk, 2008) contributed a qualitative study on nutrition-based initiatives within the Feeding America Network food banks (Kirkpatrick & Tarasuk, n.d.). Notably, these studies predominantly originate from the United States and Canada, reflecting the prominence of these countries in food bank research.

Cluster 2 – GREEN-Canada as a case study of the political implications of charitable food assistance

Cluster 2 includes 15 papers primarily featuring Canadian research, with Tarasuk contributing five papers and Riches three. Additional Canadian scholars such as Kirkpatrick, Irwin, Starkey, Teron, and Vozoris echo a strong national focus. However, the common thread beneath this cluster extends beyond its geographical scope to explore charities' sociopolitical and governmental impacts on welfare systems and the limitations of food banks. Daponte and Bade (Daponte & Bade, 2006) critique the diminished U.S. governmental programs tackling food insecurity, which has resulted in a dependence on private food assistance, with charities compensating for the shortcomings of the public safety net. Kirkpatrick and Tarasuk (Kirkpatrick & Tarasuk, 2009) challenge public health practitioners to evaluate food aid programs critically and advocate for policy reforms aimed at securing adequate food resources for low-income families. Poppedieck argues that food banks have inadvertently allowed the persistence of poverty by assuming roles traditionally filled by public policy (Olson, 1999). Riches (Riches, 2011) and Tarasuk (V. Tarasuk, 2005) delve into the contradictory existence of food banks, suggesting that while they offer temporary relief, they also perpetuate the dependency on charity and hinder the political resolution of hunger. Furthermore, Tarasuk (V. S. Tarasuk, 2001) and Tarasuk and Eakin (V. Tarasuk & Eakin, 2003) observe that food banks often fail to address the root causes of poverty, leading to superficial palliation of the issue. Consumer perspectives are also explored, with Starkey (Starkey *et al.*, 1998) pioneering the investigation into the sociodemographic and nutritional profiles of Canadian food bank users – a line of inquiry extended by Teron and Tarasuk (Teron & Tarasuk, 1999), who examined consumer perceptions of charitable food assistance. Vozoris and Tarasuk (Vozoris & Tarasuk, 2003) discuss the complex health challenges faced by economically disadvantaged households.

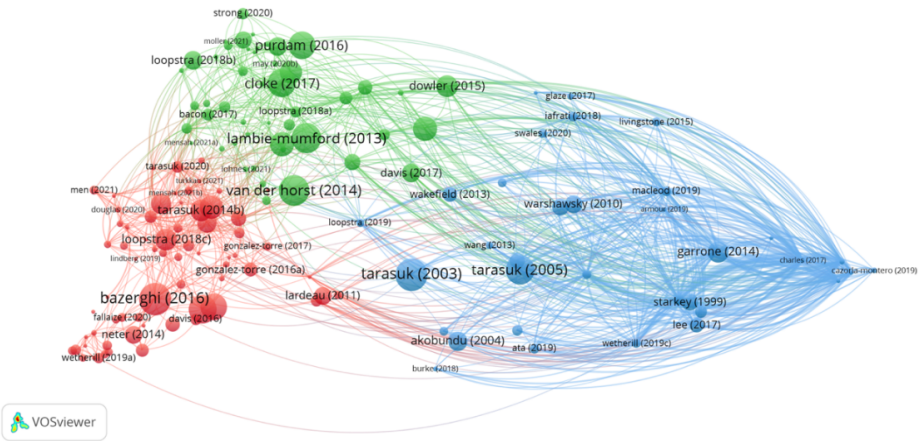
Cluster 3 – BLUE-The context and profile analysis of food banks' beneficiaries

The third cluster centers on the sociopolitical context and beneficiary profiles of food banks, with a particular focus on the United Kingdom. This cluster draws on the expertise of UK-focused authors such as Dowler, Lambie-Mumford, Loopstra, Purdam, and Perry. Perry (Perry *et al.*, 2014) pioneered the investigation into the causes behind food bank usage and potential interventions by investigating the precipitating factors of food bank use and potential mitigation strategies. Garthwaite (Garthwaite *et al.*, 2015a) delve into the health dimensions of British food bank users and provide an ethnographic perspective on their livelihood. Purdam (Purdam *et al.*, 2016a) underscores the stigmatization surrounding poverty and malnutrition through surveys and case studies. Dowler's work probes the sociopolitical determinants affecting food access in impoverished Irish and UK households (Dowler & Lambie-Mumford, 2015). Some of the documents in this cluster specifically focus on recipients of food banks and examine their political, social, and economic context within the United Kingdom. Lambie-Mumford advocated for a human rights-based approach in food policy research, (Lambie-Mumford, 2013) while Lambie-Mumford and Dowler provided a critical assessment of food aid knowledge in the UK (Dowler & Lambie-Mumford, 2015). The research in this cluster expands to include beneficiary profiles in other regions, with Van der Horst assessing the social status and emotional responses of food bank users in the Netherlands. In Canada, Loopstra depicted food bank users as a significant subset of the food-insecure population, detailing their characteristics and advocating for strategic approaches to UK food insecurity that address its socioeconomic roots (Loopstra & Lalor, 2017). Riches (2014) examines the emergence of food charities and corporate-sponsored food banks in affluent societies, questioning their efficacy in curbing the rise of hunger and food poverty (Riches & Silvasti, 2014). Cloke *et al.* (Cloke *et al.*, 2016) present an alternative view of food banks as spaces fostering political and moral values.

2.4. *Bibliographic coupling*

Figure 7 displays the network structure resulting from the bibliographic coupling analysis, showing the 150 most prominent articles within the full network. This intricate network is organized into three primary clusters of interconnected research, each representing a collective thematic focus within the field. The largest cluster consisted of 67 articles, the second contained 49 articles, and the last contained 34 articles.

Figure 7 - Bibliographic coupling using VoSviewer



Cluster 1 – RED-The health and nutritional implications of food banks and their barriers to the right to health

The first cluster, comprising articles from 2009 to 2022, addresses the health, well-being, and nutritional impacts of food insecurity. The documents in this cluster examined the triple burden of malnutrition, including undernutrition, micronutrient deficiencies, and obesity, and its associations with global health challenges. Stowers highlighted disparities in food access and representation (including unequal access to unhealthy food, media stereotypes about food pantry clients, community mistrust, lack of inclusion in food bank leadership, and limited access to information), contributing to obesity risk in food insecure populations (Stowers *et al.*, 2022). This cluster also explored specific at-risk groups, such as those with type 2 diabetes, with Cheyne evaluating an intervention aimed at these individuals within food banks (Cheyne *et al.*, 2020).

Several studies have assessed the expansion of access to healthy foods in food pantries, including Chapnick who investigated the factors that help or hinder the expansion of access to healthy foods in food pantries, (Chapnick *et al.*, 2019) and Bryan, who analysed the nutritional value of food parcels (Bryan *et al.*, 1980). Neter provide insights into Dutch food bank recipients' perceptions of food parcel content and dietary impact, (Neter *et al.*, 2020) while Chiu assess health outcomes between food bank users and nonusers (Chiu *et al.*, 2016). The nutritional quality of food parcels, benchmarked against Dutch dietary guidelines, was explored by Neter (Neter *et al.*, 2016). Nutrition -focused initiatives in the U.S. that aim to address health disparities among food aid clients are discussed by Wetherill (Wetherill *et al.*, 2019)

The predominant focus of public health-related articles is on Canada and the U.S. In Canada, Tarasuk authored two significant papers in 2014 examining the role of food banks in the welfare system. The first paper critiques the deep integration of food banks into the Canadian welfare landscape, arguing that their growth has coincided with the erosion of the welfare state. This highlights how these volunteer-run, extragovernmental food assistance programs have become supplements to publicly funded social assistance, potentially undermining them (Tarasuk *et al.*, 2014a). The second paper questions the efficacy of food banks in addressing food insecurity, pointing out their role as the primary source of immediate relief in the absence of public programs or policy interventions in Canada (Tarasuk, 2014) but also noting their limitations.

McIntyre (2016) explore public health perspectives on food waste (Mcintyre, 2010), while in the U.S., the impact of federal policies on healthy food donations to food banks was reviewed by Hudak, who investigated the regulatory environment of such donations (Hudak *et al.*, 2022).

The role of food banks during the COVID-19 pandemic has also been a focal point. Higgins *et al.* (analysed accessibility changes to food services in Hamilton, Ontario, emphasizing their critical support during economic disruptions (Higgins *et al.*, 2020). Janda highlighted the escalation of food insecurity in the U.S. as a public health concern due to the pandemic (Janda *et al.*, 2021). Men and Tarasuk report on federal assistance programs aimed at mitigating the pandemic's impact, including funding for food charities (Men & Tarasuk, 2021). Finally, Hudak evaluate pandemic-related policies promoting healthy food donations and their variability across states (Hudak *et al.*, 2022).

Cluster 2 – BLUE-The role of food banks within the decade of Austerity in the UK

The articles in the second cluster critically examine the repercussions of UK austerity policies on food bank reliance and the broader landscape of food insecurity. This paper presents a detailed inquiry into the complexities food banks face and the demographic nuances of their clientele. The second cluster presents a thematic synthesis of how austerity measures in the UK have intensified the reliance on food banks, signifying deeper socioeconomic and policy-related issues. This collection of research provides a cohesive argument that austerity has not only led to a quantitative increase in food bank usage but also qualitatively transformed the role of food banks in the social welfare landscape. At the heart of this cluster is a critical examination of the complex relationship between public policy and food insecurity: collectively, these studies reveal that food banks, while pivotal in immediate hunger relief, have become embedded within a system that increasingly

delegates welfare responsibilities to charitable organizations, raising concerns about the sustainability of this model.

The cluster critically evaluates the role of food banks within the austerity-driven welfare paradigm, suggesting a systemic shift wherein food banks are increasingly becoming substitutes for formal social support mechanisms. Lambie-Mumford's empirical work links the rise in food bank usage directly to austerity policies (Lambie-Mumford & Sims, 2018), while Garratt suggests that user estimations underestimate the true reliance on these services due to methodological oversights (Garratt, n.d.). May expand this discourse to rural areas, evidencing that food bank use is not solely an urban phenomenon but rather a nationwide challenge exacerbated by austerity (May *et al.*, 2020b).

Research within this cluster delves into the intricacies of food bank clientele vulnerabilities, with Loopstra presenting a nuanced analysis of those disproportionately affected by austerity, such as individuals with disabilities or mental health issues (Loopstra, 2018a). This is complemented by comprehensive demographic analyses from Power (Power *et al.*, 2020) (Power *et al.*, 2018) which revealed the diversity of food bank users and the exclusion of certain groups, highlighting the need for inclusive food distribution policies. This synthesis highlights the nuanced health perspectives of food bank users, portrayed in studies such as Garthwaite, which assess the health perceptions and challenges faced by users during a public health crisis (Garthwaite *et al.*, 2015). Dowler and Thompson further explored the intersection of food insecurity with health, linking budgeting constraints in food-insecure households to adverse health outcomes (Thompson *et al.*, 2018) (Dowler & Lambie-Mumford, 2015).

The emotional and psychological dimensions of food bank use are poignantly captured by Purdam who interrogate the denial of poverty among food bank users (Purdam *et al.*, 2016). The scrutiny of food bank referral systems by May (May *et al.*, 2019, 2020) and the critical perspectives of Strong (2019) add depth to the analysis of the complex dynamics within food banks and their broader social implications (Strong, 2019).

The lived experiences of food bank users are vividly brought to light through the contributions of Douglas and Clair who provide insights into the struggles with housing insecurity and food access. (Douglas *et al.*, 2015) (Clair *et al.*, 2020). Loopsta contribute to the socioeconomic discourse, examining the fallout from punitive unemployment insurance sanctions on food bank reliance (Loopstra, 2018).

Amidst this rich tapestry of research, the COVID-19 pandemic has introduced additional layers of complexity. Oncini evaluated the adaptive responses of food banks to the crisis (Oncini, 2021), and Möller took a Foucauldian perspective to analyse the power dynamics reshaped by the pandemic within UK food banks (Möller, 2021).

Cluster 3 – GREEN-Food banks as a tool to progress towards responsible consumption and production

This cluster critically examines the intersection between food waste, the operational mechanisms of food banks, and their contributions to mitigating food insecurity, directly engaging with the SDGs of "No Hunger" and "Responsible Food Consumption". This finding underscores the pivotal role of food banks in managing food oversupply by redistributing surpluses to charitable organizations, as foundational work by Tarasuk and Eakin (Tarasuk & Eakin, 2005) suggests. The cluster articulates a multifaceted narrative that not only highlights the operational challenges and strategies of food banks but also situates them within a broader context of sustainability, policy innovation, and community empowerment.

Hermsdorf delve into the nuances of food waste in Germany, attributing it to oversupply and overconsumption, thereby identifying a critical area where food banks can intervene (Hermsdorf *et al.*, 2017). Brock and Davis explored the intricate balance between the demand and supply of food, emphasizing the importance of inventory management in food banks (Brock & Davis, 2015). This analysis is complemented by Garrone's Italian case study, which assesses the donation process of surplus food to food banks, highlighting logistical considerations and the need for efficient collection strategies (Garrone *et al.*, 2014). Iafrati (Iafrati, 2018) provides an insightful examination of food banks in England, focusing on their sustainability in balancing demand and supply. Jereme *et al.* (Jereme *et al.*, 2017), in their Malaysian study, argue for the strategic establishment of food banks to alleviate food insecurity and its adverse impacts, suggesting a geographically informed approach to food bank operations.

The cluster also sheds light on gleaning as an effective method to reduce food waste, supported by Vitiello (Vitiello *et al.*, 2015), who noted its dual role in supporting food banks and empowering communities towards self-sufficiency, marking a shift towards food justice and security. Polackova and Poto (Polackova & Poto, 2017) call for a re-evaluation of the discourse around food waste prevention, advocating for new terminology that reflects the evolving landscape of food security challenges. Kinach, Parizeau, and Fraser (Kinach *et al.*, 2020) explore the incentives for food donation through tax credits in Ontario, examining policy mechanisms that encourage food redistribution. Finally, Trzaskowska (Trzaskowska *et al.*, 2020) emphasized the critical role of guidelines in managing the quality of food components near or after their minimum durability dates, aiming to mitigate food waste through regulatory standards.

The combined use of co-citation and bibliographic coupling analyses provides a comprehensive understanding of both the intellectual foundations and the current research trajectories on food banks.

Together, these analyses reveal a dynamic and evolving research landscape. Initial scholarly attention focused predominantly on food banks as responses to food insecurity and poverty, often framed within the broader context of welfare retrenchment. The focus on specific areas, namely Canada and UK, testifies to a certain concentration and productivity of researchers in these countries. It is also very interesting how the profiling of beneficiaries characterizes one of the cluster, to demonstrate a certain stigmatization of those who need food aid.

Over time, however, research has expanded to explore the broader implications of food banking, including its intersections with public health, nutrition, environmental sustainability, and social justice. Notably, recent studies have investigated how food banks operate within systems of food waste management, their role in addressing dietary inequality, and their place within austerity-driven welfare regimes. The bibliographic coupling frames food banks in a novel perspective of welfare regulator, capable of converting surpluses into supplementary support for food security, thus providing a role as a social equalizer.

3. Discussions, Conclusions and Limitations

The bibliometric analysis of the literature concerning food banks from 1997 to 2022 revealed significant trends, key contributors, and thematic clusters that provide a comprehensive overview of the field's evolution. The increasing volume of publications, especially post-2015, aligns with the global momentum towards achieving sustainable development goals (SDGs), underscoring the critical role of food banks in addressing "No Hunger" and promoting "responsible consumption and production". The distribution of publications over the years shows a right-skewed trend, highlighting a continuous expansion in this field of study, with an average of 49.5 articles published annually in the last decade. This trend signifies the recognition of food banks as practical tools for food aid within the broader context of sustainable food systems. The literature on food banks has greatly grown during the last decade, along with its multidisciplinary nature. Recent developments have highlighted the essential role of food banks in the improvement of food insecurity and food waste. Moreover, the uncertainty in food systems following COVID-19, the Russian invasion of Ukraine and the worsening of the global economic situation have exacerbated inequalities; therefore, there is a need for food banks that can help end households' food insecurity and poverty.

The analysis of international contributions and collaboration networks highlights the United States and Canada as leading contributors to food

bank research. This prominence reflects the extensive research activities and long-standing engagement with issues of food insecurity and waste in these countries. Moreover, the network analysis reveals robust collaborative ties, particularly with the USA at the center, indicating that a vibrant international research community focused on food bank studies. The collaboration between developed and developing countries enriches the global understanding of food banks, suggesting that diverse socioeconomic contexts offer valuable insights and novel approaches to food aid.

The analysis of WoS categories and journals revealed that the study of food banks is highly multidisciplinary, as confirmed by further in-depth analysis. The evolution of research themes, as depicted through the timeline of keywords, illustrates the dynamic nature of food bank studies. Initially, centred on basic issues of food security and health, the discourse has broadened to encompass topics such as welfare reform, climate change, and sustainability. This thematic expansion reflects the complex challenges faced by food banks and the need for integrated solutions that address food insecurity within the framework of sustainable development.

The co-citation analysis and bibliographic coupling conducted within this study have provided a multidimensional view of the scholarly landscape surrounding food bank research, revealing interconnected themes, pivotal contributions, and evolving trends that have shaped the discourse from 1997 to 2022. From the co-citation analysis, a clear delineation of three primary research clusters emerges, each representing distinct aspects of food bank research: the operational challenges and health implications associated with food banks, their sociopolitical context within austerity measures, and the strategies for enhancing food security and sustainability.

This segmentation underscores the multidisciplinary nature of food bank research, spanning public health, social policy, and environmental sustainability. Bibliographic coupling further emphasizes the significance of these thematic clusters, presenting a network of research that not only delves into the immediate logistical and health-related challenges of food banks but also explores their broader implications within societal and policy frameworks. The prevalence of studies focused on the health outcomes of food bank users and operational strategies for managing food waste indicates a shift towards a more holistic understanding of food banks' roles in society. Both analyses collectively highlight the dominant role of the United States and Canada in food bank research, reflecting these countries' long-standing engagement with food insecurity issues. However, the international collaboration network suggests that insights and methodologies from these regions are being integrated with global perspectives to address food insecurity in diverse socioeconomic contexts.

The co-citation and bibliographic coupling analyses underscore the evolving nature of food bank research, which has grown to encompass a wide range of issues, from health implications and operational challenges to sociopolitical impacts and sustainability concerns. This evolution reflects a broader understanding of food banks not only as emergency interventions but also as integral components of a comprehensive strategy to combat food insecurity and promote sustainable food systems. The findings call for ongoing interdisciplinary research to adapt food bank practices to contemporary challenges and opportunities, ensuring their effectiveness in addressing the complex dynamics of food insecurity in the modern world.

The findings of the study support the view that food banks are increasingly embedded within broader socio-political dynamics. The expansion of food bank activity, particularly in high-income countries, reflects a significant shift from state-centered welfare provision to charity-based models of food aid. This trend has been widely discussed in the literature as symptomatic of welfare retrenchment, where structural responses to poverty and food insecurity are replaced by voluntary, often under-resourced, interventions.

At the same time, food banks are being reframed not only as emergency responses, but as institutional actors contributing to global policy agendas, particularly Sustainable Development Goals 2 ("Zero Hunger") and 12 ("Responsible Consumption and Production"). The growing multifunctionality of food banks suggests the need for a more systemic and policy-integrated approach, in which food banks are not isolated actors but part of coordinated strategies addressing both immediate needs and structural causes of food insecurity.

Although the two analysis map very well the literature, some gaps in the literature emerge. In fact, most of the publications identified in both the co-citation and bibliographic coupling networks originate from high-income countries, namely Canada, the United States, and the United Kingdom. This geographical concentration suggests that existing knowledge may be limited in scope, shaped by specific welfare models and socio-economic contexts that are not generalizable globally. Despite their different nuances, the three countries are fully included among the democracies with the greatest liberal economic orientation. It would be very interesting to understand how food banks work even in countries that can be identified as social democracies, where welfare systems function more pervasively.

Moreover, There is also a great lack of knowledge and understanding of how food banks work in countries where informal networks and bottom-up initiatives play a fundamental role in coping with food insecurity, in particular in the Global South.

Finally, the role of food banks must also be reconsidered in light of climate change and its multifaceted impacts on food systems. Extreme weather

events and declining agricultural productivity are likely to intensify food insecurity, particularly among already vulnerable populations, especially in less developed countries. Moreover, by diverting surplus food from landfills and redistributing it to those in need, food banks play a role in reducing greenhouse gas emissions associated with food waste, aligning with climate mitigation goals. However, this ecological function is still under-theorized in the literature, and further research is needed to explore how food banks can be better integrated into climate adaptation and sustainability frameworks.

Interdisciplinary research and cross-sectoral dialogue are essential to move beyond short-term mitigation towards durable, equitable food system transformations.

This study has several limitations. First, publications that have not been cited are not of poor quality, and surely, some interesting pieces of research have been omitted from this analysis because they have not been cited enough or for several other reasons. Moreover, probably because of culture and the predominance of Western institutions, some articles written outside the Western Hemisphere were not considered because of disparities in citation practices. In fact, even if uneven, the predominant body of research was to be found among a limited number of countries; since it is more common for authors to reference other familiar authors and institutions, they can be attributed to the circumscribed nature of the field, but one the other could have overemphasized bias in the research. Furthermore, the databases can be biased towards studies in the English language and issues surrounding multiauthorship.

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The Linkage Between Livelihood Assets and Technical Efficiency of Cocoa Farmer Households in East Java Province, Indonesia

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Abstract

The study aims to investigate the linkage between the livelihood assets of cocoa farming households and the technical efficiency of cocoa farmers in East Java Province. The survey method was used to achieve the research objectives. Analysis data was divided into 3 parts, including the concept of livelihood assets with pentagonal assets used to analyze the level of livelihood assets of cocoa farmer households, stochastic frontier production used to estimate the technical efficiency of cocoa farming, and the linkage between livelihood assets and technical efficiency is analyzed using Rank Spearman correlation. Theresults show that the livelihood assets of cocoa farmer households in both Banyuwangi and Trenggalek Regencies are included in the moderate category with an average score of 3.17 and 3.33. The technical efficiency of cocoa farming in Banyuwangi is 60.74% while Trenggalek is 80.12%. The linkage between livelihood assets and technical efficiency in Banyuwangi is weak, while Trenggalek is moderate.

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Introduction

East Java Province is one of the cocoa commodity development areas on the island of Java. Several districts in East Java Province are developing cocoa as a source of community income, opening new job opportunities, and improving the regional economy such as Banyuwangi and Trenggalek Regency. Banyuwangi Regency is a cocoa-producing center in East Java with a planting area of 9,590 Ha and production of 7,800 tons in 2021 (BPS Jawa Timur, 2023). Banyuwangi is also known for having cocoa beans which are in demand by domestic and international markets. Banyuwangi produces a lot of plantation cocoa and smallholder cocoa. Apart from Banyuwangi, Trenggalek is also one of the cocoa producers in East Java Province with relatively high production. Data for 2021 shows that Trenggalek has a planting area of 1,669 Ha with production of 1,180 tons (BPS Jawa Timur, 2023). This makes Trenggalek ranked fourth as the largest cocoa-producing area in East Java. Trenggalek Regency also produces a lot of smallholder cocoa. Interestingly, the cocoa cultivated by cocoa farmers in Trenggalek, specifically in Suruh village, has switched to organic farming (Fitriyah & Hariyati, 2020).

The condition of cocoa in East Java, both Banyuwangi and Trenggalek, often faces various classic problems, such as: 1) climate change causes unpredictable rainfall and rising temperature (Hutchins *et al*., 2015) so that the rainy season is prolonged which has an impact on increasing pest and disease attacks on cocoa plants (Skendžić *et al*., 2021) thereby reducing productivity and cocoa production (Amfo *et al*., 2021; Wongnaa & Babu, 2020), 2) Land area is getting narrower and decreasing as a result of the shift in commodities from cocoa to other commodities (Asante-Poku & Angelucci, 2013; Asubonteng *et al*., 2018), 3) the use of less superior cocoa seeds led the cocoa plants to produce unhealthy cocoa pods, thereby reducing productivity (Effendy *et al*., 2019), 4) Farmers have old cocoa plants that are easily attacked by pests and disease (Binam *et al*., 2008; Iskandar *et al*., 2020; Kongor *et al*., 2018; Schaad & Fromm, 2017), 5) Farmers have not processed fermented beans or prefer to produce unfermented cocoa beans, this causes the beans produced to be of low quality which has an impact on the low price of cocoa beans (Prihadianto *et al*., 2022; Rifin, 2020), and 6) lack of synergy among institutions at the farmer level causes farmers to have a weak bargaining position (Basri *et al*., 2023; Prihadianto *et al*., 2022).

Those conditions cause cocoa farmers to try to optimize the potential of their resources. Therefore, farmers as drivers in cocoa farming are required to carry out various activities for the survival of their households. Furthermore, the differences in the characteristics of cocoa farming in the two regions, both in Banyuwangi and Trenggalek, can be investigated by

using the concept of livelihood. Through the livelihood concept, farmers' ability to face pressures and shocks in managing resource ownership and other activities that provide income can be known, so that farming households can survive and adapt to environmental change (Scoones, 1998). It helps cocoa farming households in both Banyuwangi and Trenggalek to improve their household welfare.

Furthermore, the problems faced by farming households in cultivating cocoa plants have resulted in a decline in cocoa production, thus requiring farmers to use optimal production inputs. Decreasing cocoa production cannot be separated from the use of inadequate inputs. This is caused by the limited use of fertilizer by farmers due to scarce fertilizer availability and high fertilizer prices, ineffective use of pesticides, and high labor costs. The use of inputs in inappropriate quantities and combinations will affect the output of cocoa farming. The combination of a given input to produce the given output can be determined by measuring the technical efficiency (TE) (Lovell, 1993).

A high level of TE indicates that farmers are achieving their potential production. High cocoa production is able to provide higher income for cocoa farming households, so that farming households are able to improve their welfare. On the other hand, farming households with high livelihood assets are able to meet living needs to continue the survival of their household, one of which is through cocoa farming. Studies on livelihood assets (Illu *et al.*, 2021; Lawal *et al.*, 2011; Li *et al.*, 2014; Roslinda *et al.*, 2024; Saleh *et al.*, 2016; Shivakoti & Shrestha, 2005; Tefera *et al.*, 2004; Udoh *et al.*, 2017) focuses on the livelihoods of farming households. Studies on TE (Attipoe *et al.*, 2020; Besseah & Kim, 2014; Binam *et al.*, 2008; Donkor *et al.*, 2023; Ofori-Bah & Asafu-Adjaye, 2011; Rouf *et al.*, 2021) with a focus on cocoa farming have also been widely carried out. High livelihood assets, particularly in the form of human capital such as education level, play a crucial role in enhancing technical efficiency by supporting farmers' managerial abilities, insights, and adaptability to new technologies in managing farm inputs (Asri *et al.*, 2019; Uloh & Abor, 2019). These skills enable more accurate input allocation, allowing farmers to achieve higher technical efficiency and maximize output (Effendy *et al.*, 2019). The resulting increase in output directly boosts income, which in turn strengthens household livelihood assets through the accumulation of productive resources (Bezemer *et al.*, 2005; Eman *et al.*, 2022). Therefore, there is a clear relationship between livelihood assets and technical efficiency. For this study, we analyzed both the livelihood assets of cocoa farming households and the TE of cocoa farming, as well as the linkage between livelihood assets and the technical efficiency of cocoa farming households in East Java Province. This study is an extension of the extant literature and will contribute to the literature on livelihood assets and TE. It will also

provide necessary information for policymakers to improve the productivity of Indonesian cocoa, especially in smallholder cocoa.

1. Materials and Methods

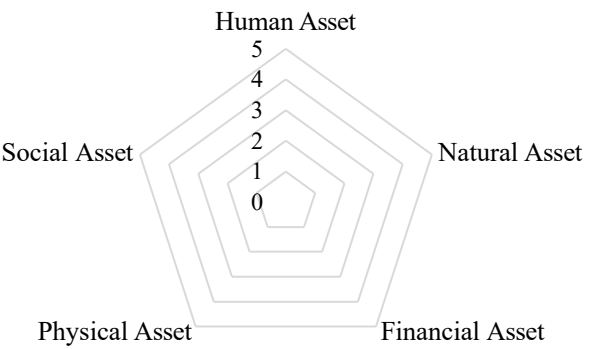
Study Location and Sampling

The study was conducted in Banyuwangi and Trenggalek Regencies, East Java Province, Indonesia. Study location selection was determined using a purposive method. The location was chosen on the basis that those areas are two cocoa commodity centers in East Java Province (BPS Jawa Timur, 2023). The basic method used in this study was a survey. A survey is an investigation carried out to obtain facts from existing phenomena and seek factual information from a group or region and can be carried out by census or using samples (Sugiyono, 2017). The survey was conducted by randomly taking respondents from 100 cocoa farming households. We randomly selected 50 heads of families in each district. The number of respondents was able to produce and describe diverse data according to the research conditions (Sugiyono, 2017). A semi-structured questionnaire was used to collect the data. The field survey was conducted in the period July to December 2023.

Analytical Framework

Analysis of livelihood assets used a livelihood asset pentagon which aims to describe the relationship of the five assets, i.e., human, natural, social, financial, and physical (DFID, 2000; Ellis, 2000), owned by cocoa farming households, which is presented in Figure 1.

Figure 1 - Livelihood Assets Pentagon



Each asset was measured based on asset-measuring variables which consist of several indicators. The measuring variables for each asset are contained in Table 1.

Table 1 - Variables and Indicators of Livelihood Assets

No.	Variables	Indicators
1.	**Human Asset**	1. Education Level 2. Training Participation 3. Health Condition 4. Nutritional Status 5. Involvement of household members in farming 6. Knowledge of healthy plants 7. Knowledge of plant preservation 8. Knowledge of post-harvest processing 9. Knowledge of marketing 10. Activeness in farmer groups
2.	**Natural Asset**	1. Land occupancy status 2. Land use 3. Availability of water 4. Overview of rainfall 5. Water source 6. Opportunity to obtain organic fertilizer 7. Opportunity to obtain inorganic fertilizer 8. Opportunities to obtain labor 9. Overview of the level of erosion 10. Overview of the level of land damage
3.	**Financial Asset**	1. Primary source of income 2. Average primary income in a year 3. Other sources of income 4. Cocoa farming income 5. Adequate household income 6. Ownership of savings 7. Loan involvement for household needs 8. Loan involvement for farming development 9. Sources of loan for household needs 10. Sources of loan for farming development
4.	**Physical Asset**	1. Condition of road facilities 2. Distance to the farming location 3. Condition of residence 4. Home ownership status 5. Overview of farming land 6. Transportation facilities

No.	Variables	Indicators
		7. Communication facilities 8. Information sources 9. Electrical power 10. Access to household necessities
5.	**Social Asset**	1. Communication with neighbors 2. Communication with farmer group administrators 3. Communication with other farmer groups 4. Communication with village officials 5. Communication with farming partners 6. Communication with agricultural extension workers 7. Communication with cooperative institutions 8. Communication with collecting traders

Source: DFID, 2000; Ellis, 2000; Scoones, 1998.

Each indicator was measured by giving a score of 1 to 5. The asset pentagon calculation used the average score of each household's livelihood asset score with a formula:

$$\text{Asset score} = \frac{\sum \text{scores of each asset}}{\sum \text{indicators of each asset}}$$

The average score is used to see the level of livelihood assets of cocoa farming households. The criteria for livelihood asset levels are divided into three categories (Fariz *et al.*, 2022), in the following ranges :

1. Low: $1{,}00 < x \leq 2{,}33$
2. Moderate: $2{,}34 < x \leq 3{,}66$
3. High: $3{,}67 < x \leq 5{,}00$

Factors influencing smallholder cocoa farming in East Java Province in this study were analyzed using the stochastic frontier production function (SFPF). The SFPF estimation model for cocoa farming uses the Cobb-Douglass model with the formula in equation 1 (Bhanumurthy, 2002; Mahaboob *et al.*, 2019).

$$Y = \beta_0 X^{\beta 1} X^{\beta 2} X^{\beta 3} X^{\beta 4} e^{\varepsilon i} \quad (1)$$

Notes:
Y: Production (kgs)
β_0: Intercept
β_i: Coefficient

X_1: Land area (Ha)
X_2: Inorganic or Organic Fertilizer (kgs)
X_3: Chemical or biological pesticides (liter)
X_4: Labor (man-day)
e_i: Error term

Next, the technical efficiency of cocoa farming is estimated using the formula in equation 2 (Coelli *et al*., 2005; Porcelli, 2009).

$$TE_i = \frac{Y_i}{Y_{i^*}} = e^{-ui} = \exp(-u_i) \quad (2)$$

Where:
TE_i: Technically Efficiency of farmer *i*
Y_i: Actual output for farmer *i*
exp(-ui): Estimated output for farmer *i*
u_i: Technical efficiency of farmer *i*

Technical efficiency ranges from $0 < TE_i < 1$. Farmers with a TE of more than 0.70 are classified as technically efficient, while farmers with a TE of less than 0.70 are classified as technically inefficient (Kumbhakar & Lovell, 2000; Sumaryanto, 2001).

The linkage between farming household livelihood assets and the technical efficiency of cocoa farming is analyzed using Rank Spearman correlation in equation 3 (Chen &Popovich, 2002).

$$r_s = 1 - \frac{6 \sum d_i^2}{n(n^2 - 1)} \quad (3)$$

Description:
r_s: Spearman's rank correlation coefficient
d_i: The difference between the ranks of the i-th pair of observations on the two variables
n: The number of observation

The correlation coefficient ranges from –1 to +1. If the r value is positive, it indicates a positive correlation and the r value is negative, indicating a negative correlation. Correlation coefficient categories include: < 0.20 = very weak; < 0.40 = weak; < 0.60 = moderate; < 0.80 = strong; and < 1.00 = very strong.

2. Results

Livelihood Assets of Cocoa Farming Household in East Java Province, Indonesia

The concept of livelihood is related to household management of the resources and assets they own. Ellis (2000) stated that livelihood comprises the assets (human, natural, financial, physical, and social assets), the activities, and the access to these (institutions and social relations) that determine the living gained by individuals or households simultaneously. Livelihood assets in each region vary depending on the value of each asset owned by cocoa farming households. The variations in value and linkage of assets in livelihood resources are depicted in an asset pentagon. The shape of the pentagon describes schematically variations in ownership levels and community access to assets (DFID, 2000). The wider the pentagon shape to the center point, the higher the score of livelihood assets. In contrast, the closer the pentagon shape is to the center point, the lower the asset pentagon score of a community. The livelihood assets of cocoa farming households in East Java Province can be seen in Figure 2.

Figure 2 - Livelihood Asset Pentagon of Cocoa Farming Household

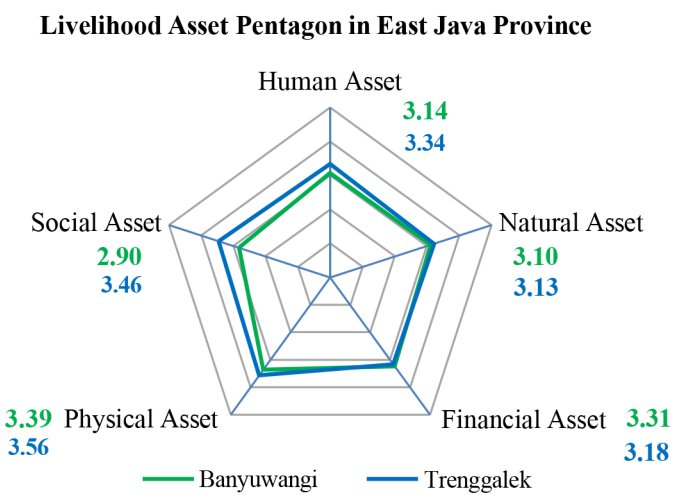


Figure 2 shows that the overall livelihood assets of cocoa farming households in both Banyuwangi and Trenggalek are in the moderate category. The average level of livelihood assets for cocoa farming households in Trenggalek is 3.35

while in Banyuwangi is 3.12. In addition, all livelihood assets, except for the financial assets of cocoa farming households in Trenggalek, are higher than in Banyuwangi. Based on livelihood assets indicators, cocoa farmers in Trenggalek are higher than in Banyuwangi in terms of education and training participation (human asset); opportunity to obtain organic fertilizer (natural assets); condition of road facilities, and overview of farming land (physical asset); and communication with the surrounding community (social asset). Meanwhile, Banyuwangi is superior to Trenggalek based on financial assets, such as indicators of other sources of income and household loans. The lowest livelihood assets score of cocoa farming households in Banyuwangi comes from DFID, (2000) social assets (2.83). This shows that there is a lack of social resource capacity for cocoa farming households in Banyuwangi to adapt to the surrounding community. According to, social resources are generally intangible and not easily measured but it is necessary and beneficial for society. Meanwhile, the lowest score for livelihood assets of cocoa farming households in Trenggalek comes from natural assets (3.13). This is due to the low availability of inorganic fertilizers and labor, most of which only come from within the family. Each indicator of livelihood assets for cocoa farming households in East Java Province is described as follows:

Table 2 - Human Asset of Cocoa Farmer Household

No.	Indicators	Banyuwangi	Criteria	Treanggalek	Criteria
1	Education Level	2.92	Moderate	3.82	High
2	Training Participation	2.20	Low	3.22	Moderate
3	Health Condition	4.84	High	3.52	Moderate
4	Nutritional Status	3.80	High	4.28	High
5	Involvement of household members in farming	1.42	Low	1.92	Low
6	Knowledge of healthy plants	3.64	Moderate	3.64	Moderate
7	Knowledge of plant preservation	3.56	Moderate	3.60	Moderate
8	Knowledge of post-harvest processing	3.72	High	2.80	Moderate
9	Knowledge of marketing	3.04	Moderate	2.92	Moderate
10	Activeness in farmer groups	2.26	Low	3.64	Moderate
	Average score	**3.14**	**Moderate**	**3.34**	**Moderate**

The indicator with the lowest score in human assets in Banyuwangi is the involvement of household members in cocoa farming (Table 2). The same condition also occurs in Trenggalek. It is because the only members of the farming household involved in cocoa farming are the head of the household and/or his wife, while other family members (the children) work in other sectors. Apart from that, in Banyuwangi, indicators of participation in training and activity in farmer groups are in the low category. Cocoa farmers in Banyuwangi are members of farmer groups, but they do not participate in decision-making on farmer group activities and are rarely involved in training activities. In line with (Zulkiflibasri *et al.*, 2022), agricultural institutions tend to be considered just a formality that causes a lack of farmer participation.

Table 3 - Natural Asset of Cocoa Farming Household

No.	Indicators	Banyuwangi	Criteria	Treanggalek	Criteria
1	Land occupancy status	3.36	Moderate	3.22	Moderate
2	Land use	3.52	Moderate	3.36	Moderate
3	Availability of water	4.56	High	4.42	High
4	Overview of rainfall	3.78	High	3.82	High
5	Water source	2.56	Moderate	2.74	Moderate
6	Opportunity to obtain organic fertilizer	1.62	Low	3.32	Moderate
7	Opportunity to obtain inorganic fertilizer	2.12	Low	1.00	Low
8	Opportunities to obtain labor	1.20	Low	1.78	Low
9	Overview of the level of erosion	4.18	High	3.88	High
10	Overview of the level of land damage	4.06	High	3.78	High
	Average score	**3.10**	**Moderate**	**3.13**	**Moderate**

Table 4 - Financial Asset of Cocoa Farming Household

No.	Indicators	Banyuwangi	Criteria	Treanggalek	Criteria
1	Primary source of income	2.62	Moderate	3.62	Moderate
2	Average primary income in a year	2.64	Moderate	2.14	Low
3	Other sources of income	3.06	Moderate	2.26	Low
4	Cocoa farming income	2.12	Low	3.04	Moderate
5	Adequate household income	3.12	Moderate	3.18	Moderate
6	Ownership of savings	1.92	Low	2.24	Low
7	Loan involvement for household needs	4.30	High	3.68	High
8	Loan involvement for farming development	4.34	High	3.84	High
9	Sources of loan for household needs	4.48	High	3.74	High
10	Sources of loan for farming development	4.54	High	4.06	High
	Average score	**3.31**	**Moderate**	**3.18**	**Moderate**

Table 3 shows that opportunities to obtain organic fertilizer, inorganic fertilizer, and labor are indicators in the low category in Banyuwangi. The same conditions, except for the opportunity to obtain organic fertilizer, also occur in Trenggalek. The low opportunity to get fertilizer is caused by scarce fertilizer availability and increasingly high fertilizer prices, so farmers rarely fertilize their cocoa plants. The conditions are different in Trenggalek in obtaining organic fertilizer, where farmers produce organic fertilizer independently to meet the nutrient needs in the soil for cocoa plants. Obtaining labor is also quite limited because the opportunities to obtain labor are relatively small, especially labor from outside the family, so many farmers only use labor from within the family. The overview of the level of erosion and land damage has the opposite meaning, both indicators are classified as high, indicating that the two areas of Banyuwangi and Trenggalek have good land conditions and are suitable for cocoa plants.

While, Table 4 explains that in Banyuwangi, a financial asset in the low category comes from cocoa farming income. It is because cocoa farming is not the primary income in farming households. A few farmers also grow cocoa plants in their yards so the income from cocoa farming is relatively small. Another indicator in the low category is household savings ownership. Farming households in Banyuwangi prefer to use their household income to pursue other activities, such as raising livestock and trading. This aims to increase the income of farmer households apart from cocoa farming. Therefore, the farmers' household savings are relatively low.

In Trenggalek, the lowest financial asset comes from the average primary income in a year. The primary income of farming households comes from cocoa farming which is relatively small, less than IDR 10 million. Households also have savings ownership in the low category. This is because farming households not only use their income for clothing, food and shelter needs, but also for other activities such as raising livestock, trading, and farming other than cocoa. Other sources of income are classified as low because the majority of farming households in Trenggalek rely on cocoa farming as their primary source of income.

Table 5 - Physical Asset of Cocoa Farming Household

No.	Indicators	Banyuwangi	Criteria	Treanggalek	Criteria
1	Condition of road facilities	2.88	Moderate	3.56	Moderate
2	Distance to the farming location	3.60	Moderate	3.42	Moderate
3	Condition of residence	3.16	Moderate	3.56	Moderate
4	Homeownership status	4.48	High	4.70	High
5	Overview of farming land	2.12	Low	3.72	High
6	Transportation facilities	3.62	Moderate	3.24	Moderate
7	Communication facilities	3.70	High	3.58	Moderate
8	Information sources	3.28	Moderate	3.16	Moderate
9	Electrical power	3.18	Moderate	3.26	Moderate
10	Access to household necessities	3.92	High	3.44	Moderate
	Average score	**3.39**	**Moderate**	**3.56**	**Moderate**

Table 4 also shows that loan involvement for households and farming has the opposite meaning from other indicators. A high score indicates that the household has never been involved in loans for household or farming needs. In both regions, both indicators are classified as high, showing that cocoa farming households rarely or never engage in loans. This indicates that cocoa farming households in both regions are mostly able to meet their household and farming needs from cocoa farming as the primary source of income. The same thing also applies to indicators of loan sources for both household consumption and farming business development. In both regions, both indicators are classified as high, indicating that cocoa farming households have access to loans from official institutions such as cooperatives and banks. A few farmers prefer to borrow money from neighbors or moneylenders to meet their household needs. These conditions were aligned with the study of (Saleh *et al.*, 2016).

In Table 5 we know that the overview of cocoa farming land in Banyuwangi Regency is in the low category. This is because most farmers perform cocoa farming in the yard or cultivation rights on land (HGU). Cocoa plants, whether in the forest (cultivation rights on land) or yard, are planted without paying attention to effective spacing, the presence of shade trees, and plant treatment. Meanwhile, in Trenggalek, the condition of cocoa farming land is organized by adjusting the planting distance even for plants in the yard. Farmers in Trenggalek also make *rorak* (a burrow for storing water) for their cocoa plants to overcome water shortages during the dry season.

Table 6 - Social Asset of Cocoa Farming Household

No.	Indicators	Banyuwangi	Criteria	Treanggalek	Criteria
1	Communication with neighbors	4.70	High	5.00	High
2	Communication with farmer group administrators	2.58	Moderate	3.78	High
3	Communication with other farmer groups	2.54	Moderate	2.88	Moderate
4	Communication with village officials	2.72	Moderate	2.58	Moderate
5	Communication with farming partners	2.30	Low	2.82	Moderate
6	Communication with agricultural extension workers	1.86	Low	3.34	Moderate

No.	Indicators	Banyuwangi	Criteria	Treanggalek	Criteria
7	Communication with cooperative institutions	1.92	Low	3.28	Moderate
8	Communication with collecting traders	4.52	High	3.98	High
	Average score	**2.90**	**Moderate**	**3.46**	**Moderate**

Table 6 explains that in Banyuwangi, communication with farming partners, agricultural extension workers, and cooperative institutions are low. Communication with farming partners is only carried out by the farmer group leader, so farmer members rarely communicate directly with farming partners. The limited number of agricultural extension workers means that extension services are rarely carried out to farmers so communication with agricultural extension workers is limited. Even though farmers have access to cooperative institutions, only a few farmers make loans to cooperatives so communication with cooperative institutions is minimal. On the other hand, all social assets in Trenggalek are classified as moderate or high. It shows that farming households in Trenggalek have good social resource capabilities. However, farming households still need to improve communication with village officials to obtain information regarding the presence of aids, such as basic food supplies and other social aids. Likewise, communication with other partner groups and farming partners so that farmers can exchange information regarding the effective and efficient implementation of cocoa farming, both from on-farm to off-farm activities, both on-farm and off-farm activities. DFID (2000) conluded that social capital is considered to enhance mutual trust and lower the cost of working simultaneously. Furthermore, it also helps to increase people's income and savings (financial assets), is more effective in improving the management of common resources (natural assets), maintains shared infrastructure (physical assets), and facilitates the development of knowledge (DFID, 2000).

Technical Efficiency of Cocoa Farming in East Java Province, Indonesia

Cocoa farming in East Java province is influenced by land area, organic or inorganic fertilizer, biological or chemical pesticides, and labor. Farming in Banyuwnagi tends to use chemicals such as inorganic fertilizers and chemical pesticides, while Trenggalek has implemented the use of organic materials in cocoa farming such as organic fertilizers and pesticides.

Table 7 - Estimation Result of Cocoa Production Function in East Java Province

Variable	Banyuwangi		Trenggalek	
	Coeff.	**t-ratio**	**Coeff.**	**t-ratio**
Intercept	5.5468	6.4007	6.8529	27.0781
Land area	0.3758**	4.5811	0.8893**	50.0085
Inorganic/Organic Fertilizers	0.0045 ^{ns}	0.1455	0.0303^{ns}	1.1119
Biological/Chemical Pesticides	0.1413 ^{ns}	1.2701	0.0243^{ns}	0.5642
Labor	0.4823 ^{ns}	1.5674	0.2514**	3.3394
Sigma-squared (σ^2)	0.9763		0.0185	
Gamma (γ)	0.9355		0.9999	
Log-likehood function MLE	–37.8266		37.0650	
LR test of the one-side error	1.8563		3.2820	

Notes: ** significant at α 1%; * significant at α 5%; ^{ns} not significant.

Table 7 summarizes the results of estimating the production function in Equation 1. The results show that one of the four factors significantly influences the technical efficiency of cocoa farming in Banyuwangi and two factors significantly influence the technical efficiency of cocoa farming in Trenggalek. In Banyuwangi, land area has a positive and significant effect, whereas inorganic fertilizers, chemical pesticides, and labor do not have a significant effect. Meanwhile, in Trenggalek, land area and labor are factors that have a positive and significant influence on technical efficiency, on the other hand, organic fertilizers and pesticides do not have a significant influence. The sigma squared, gamma, and log-likelihood MLE values show strong estimation results. Gamma values of 0.9355 and 0.9999 mean that the model is influenced by technical inefficiency effects of 93.55% and 99.99%, while the rest is influenced by stochastic effects or random factors. Factors estimated to cause technical inefficiency in cocoa farming include age, education, number of family members, cocoa farming experience, land ownership status, gender, etc. (Attipoe *et al*., 2020; Besseah & Kim, 2014; Danso-Abbeam *et al*., 2020; Donkor *et al*., 2023; Rouf *et al*., 2021). Attipoe *et al*., (2020) added that technical inefficiency has a fundamental role in explaining output levels among cocoa farmers in a region. In our analysis, we did not include tree age as a variable due to the unavailability of this specific data during field collection. However, based on field information and interviews with local agricultural officers and farmers, we learned that cocoa planting in both Trenggalek and Banyuwangi districts was carried

out simultaneously as part of government-supported seedling assistance programs. In Trenggalek, the cocoa seedling distribution program was implemented approximately 20 years ago, while in Banyuwangi, a similar program was conducted around 15 years ago. As a result, the age of cocoa trees in each region tends to be relatively homogeneous around 20 years in Trenggalek and 15 years in Banyuwangi. While we acknowledge that tree age can influence the responsiveness of fertilizer use and yield over time in perennial crops, we believe that the relatively uniform planting time within each region helps to minimize the variability caused by tree age in this particular case. Nonetheless, we recognize this as a limitation of the study.

The land area has a positive and significant effect on cocoa production, while inorganic fertilizers, chemical pesticides, and labor have a positive and insignificant effect on cocoa production in Banyuwangi. The land area has a coefficient value of 0.3758. This value means that every 1% increase in land area will increase cocoa production by 0.3758%. On average, cocoa farmers have a land area of less than 0.5 Ha. This shows that even though cocoa farming is small-scale (smallholder cocoa), farmers have the potential to increase land area through the use of yard land and cultivation rights on land that have not been managed optimally. If cocoa production is to be increased, the area of land cultivated by farmers must also be increased. This result is similar to (Effendy *et al*., 2019; Rahman & Hariyati, 2023; Rouf *et al*., 2021). Inorganic fertilizers and chemical pesticides do not have a significant effect on cocoa production. This is because the older cocoa plants (in Banyuwangi, the cocoa plants are about 22 years old) make the use of fertilizers and pesticides less effective in increasing cocoa production. Furthermore, a few farmers do not treat their cocoa plants properly, including using fertilizers and pesticides in cocoa farming. Farmers assume that cocoa plants will still produce fruit even if the cocoa plants are not treated properly (Rahman & Hariyati, 2023). Labor also does not have a significant effect on cocoa production. Older cocoa plants and the density of plants in the cocoa plantation area cause the use of labor to preserve and treat cocoa plants to be less effective in increasing cocoa production. Farmers should replace new cocoa plants so that the use of production inputs such as inorganic fertilizers, pesticides, and labor can increase cocoa production in Banyuwangi. Binam *et al*., (2008) concluded that the cocoa tree becomes productive after four years of planting with the yields increasing annually until about 18 years, then the yields gradually begin to decline. (Binam *et al*., 2008) added that after 20-30 years of cocoa tree planting, farmers need to reinvest in uprooting, replanting, soil improvement, and future pest reduction, or migrate to a fresh area.

In Trenggalek, land area and labor have a positive and significant influence on cocoa production. Meanwhile, organic fertilizers and pesticides have a positive and insignificant effect on production. The land area has a coefficient value of 0.8893, meaning that every 1% increase in land area will increase

cocoa production by 0.8893%. Similar to farmers in Banyuwangi, cocoa farmers cultivate cocoa plants on a small scale with a land area of less than 0.5 Ha. Cocoa farmers have the potential to increase the area of cocoa through the use of yard land to increase cocoa production. These results are in line with the studies from (Effendy *et al.*, 2019; Rouf *et al.*, 2021). Labor with a coefficient value of 0.2514 means that every additional 1% of labor will increase cocoa production by 0.2514%. Increasing the use of labor will improve the efforts of cocoa plant treatment. Farmers tend to be more intensive in performing biological control, fertilization, land clearing, post-harvest handling, and others, thus it will optimize their cocoa production. This result is similar to (Attipoe *et al.*, 2020; Donkor *et al.*, 2023; Rouf *et al.*, 2021). Organic fertilizers and pesticides do not have a significant effect on cocoa production. The use of organic fertilizers and pesticides requires a longer process and time for cocoa plants to absorb nutrients and other chemical compounds contained in organic fertilizers and pesticides, therefore it takes longer for cocoa plants to produce fruit. These conditions were aligned with the findings of (Febriani *et al.*, 2021; Jatsiyah *et al.*, 2020; Sharma & Chetani, 2017). Furthermore, similar to Banyuwangi, the cocoa plants in Trenggalek are old plants, about 28 years old. Farmers need to replant their cocoa plants.

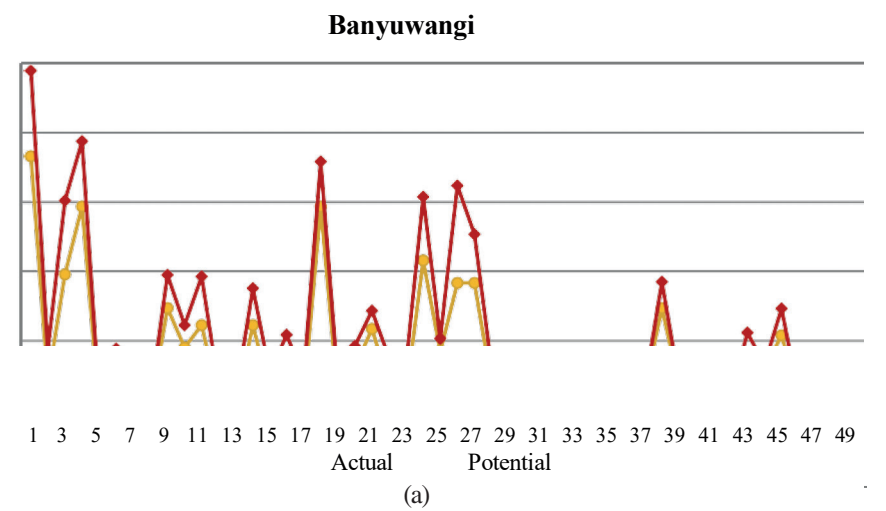
Table 8 - The Distribution of Technical Efficiency of Smallholder Cocoa Farmers

Technical Efficiency	**Banyuwangi**		**Trenggalek**	
	Number of Farmers	**%**	**Number of Farmers**	**%**
< 50	17	34	0	0
50 ≤ ET ≤ 70	12	24	9	18
70 < ET ≤ 90	20	40	33	66
> 90	1	2	8	16
N	50	100	50	100
Mean		**60.74**		**80.12**
Maximum		**91.20**		**99.94**
Minimum		**12.88**		**61.16**

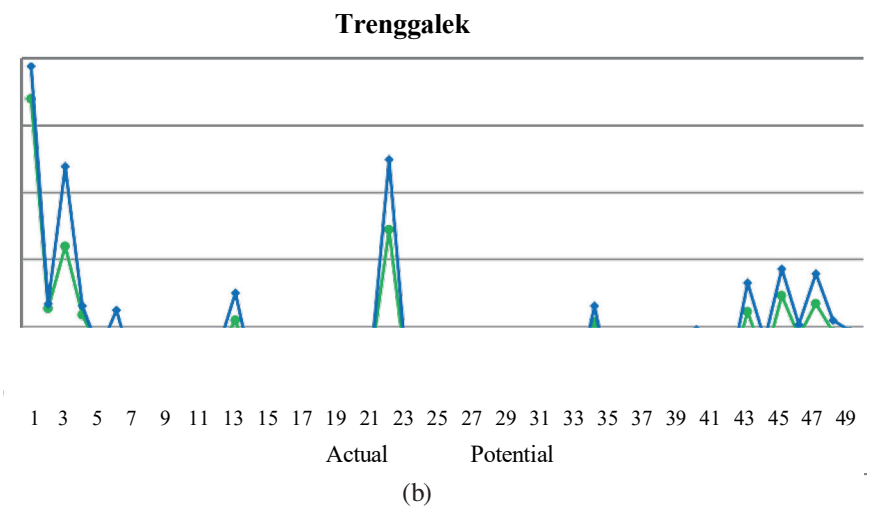
Table 8 shows that the average technical efficiency of cocoa farming in Trenggalek is 80.12% and 60.74% for Banyuwangi. The highest technical efficiency in Trenggalek and Banyuwangi are 99.94% and 91.20%, while the lowest are 61.16% and 12.88%. The majority of farmers in Banyuwangi are at a lower-level efficiency with a percentage of farmers below 70% efficiency

level of 58%. At the same level, the percentage of farmers in Trenggalek is only 18%. Farmers in Trenggalek dominate with a high level of efficiency with the percentage of farmers at a 70-90% efficiency level of 66% and 16% of farmers operating at an efficiency level higher than 90%. The percentage of farmers in Banyuwangi who operate at an efficiency level of 70-90% is 40%, and the remaining 2% of them operate at an efficiency level higher than 90%. It indicates that farmers in Trenggalek have higher technical efficiency than Banyuwangi.

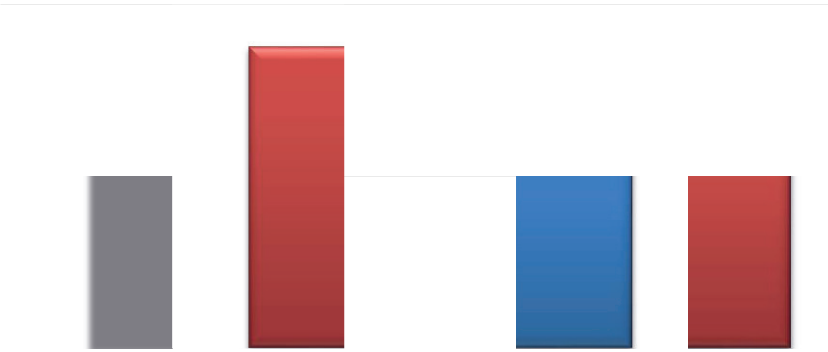
Figure 3 - Comparison of Actual and Potential Production of Cocoa Farming: (a) Banyuwangi (b) Trenggalek (c) Average Production



(a)



(b)



(c)

Figure 3 shows that the actual production of both regions is below potential production. It indicates that the level of technical efficiency of cocoa farming in both regions has not been able to reach ideal potential production. The gap between actual production and potential production can be seen from the level of technical efficiency of cocoa farming which is less than one (TE ≠ 1). The gap between actual production and potential production in Trenggalek is lower than in Banyuwangi. It is proven by the technical efficiency level of Trenggalek (80.12%) which is higher than Banyuwangi (60.74%). The higher the technical efficiency, the lower the gap between actual and potential production. Even though the technical efficiency value in Trenggalek is higher than in Banyuwangi, the actual production in Banyuwangi is still higher than in Trenggalek. This is because the land area of cocoa farmers in Banyuwangi is higher than in Trenggalek, so cocoa production in Banyuwangi remains higher than in Trenggalek. (BPS Jawa Timur, 2023) data show that the area of cocoa plantations in 2022 in Banyuwangi of 9,824 Ha with cocoa production of 8,017 tons, while Trenggalek has a land area of 4,201 Ha with cocoa production of 2,821 tons.

The Linkage of Livelihood Assets and Technical Efficiency of Cocoa Farming Households in East Java Province, Indonesia

The link between livelihood assets and the technical efficiency of cocoa farming households aims to examine the relationship between those two. Higher livelihood assets will be followed by farmers' ability to achieve higher potential production (or technical efficiency) of cocoa farming, vice versa.

The analysis results of the linkage between livelihood assets and technical efficiency of cocoa farming households in East Java province are presented in Table 8. Analysis of the relationship between livelihood and TE using Rank Spearman correlation because this analysis examines a relationship between two variables in a population as an inferential statistic (Chen & Popovich, 2002). This analysis is in line with the research of (Anandari, 2022).

Tabel 8 - The Correlation Result of Livelihood Assets and Technical Efficiency

Correlation	Banyuwangi	Trenggalek
Sig. (2-tailed)	0.032*	0.000**
Rank Spearman Correlation	0.303	0.514

Notes: ** significant at α 1%, * significant at α 5%

Table 8 explains that the correlation between livelihood assets and the technical efficiency of cocoa farmer households in both Banyuwangi and Trenggalek Regencies has a positive and significant correlation. The Rank Spearman correlation value for Banyuwangiis 0.303 meaning the correlation between the two variables is in the weak category, while Trenggalek is 0.514 meaning the moderate category. The positive sign indicates that the higher the livelihood assets of cocoa farming households, the higher the level of technical efficiency of cocoa farming, vice versa. The high livelihood assets condition of cocoa farming households shows that the household has adequate assets to meet household needs (clothing, food, shelter) as well as cocoa farming as a primary source of household income. Farming households with adequate assets will utilize the resources they have to increase their cocoa farming production. In Trenggalek, farmers have been able to independently provide production inputs such as organic fertilizers and pesticides. Meanwhile, in Banyuwangi, farmers still rely on inorganic fertilizers and chemical pesticides as input for their cocoa farming production. These efforts are performed by cocoa farmers to achieve potential production or technical efficiency. On the other hand, technically efficient cocoa farming (such as in Trenggalek) means that production resulting from cocoa farming reaches potential levels. Potential production generates sufficient household income for cocoa farmers to support the compliance of livelihood assets to meet living needs, manage existing resources, and adapt to changes.

The results of the correlation analysis between farmer household livelihood assets and the technical efficiency of cocoa farming are in the weak category.

This is because the use of livelihood assets by cocoa farming households does not focus on cocoa farming. The majority of farming households cultivate cocoa plants not as the main commodity. Farmers choose to switch to cultivating dragon fruit or durian plants, raising livestock, and trading, because the income earned is relatively higher, so households pay less attention to their cocoa farming business, especially the fulfillment of production inputs for cocoa plants such as providing fertilizers and pesticides becomes less fulfilled. It causes cocoa farming in Banyuwangi to be technically inefficient. On the other hand, inefficient cocoa farming means that farmers' cocoa production is still far from reaching production potential so that farmer household income from cocoa farming is relatively low. The low income from cocoa farming does not fully help farmers in increasing the level of livelihood assets of cocoa farming households, especially on indicators in natural, social, and human assets. Roslinda *et al*., (2024) stated that farming is a business that depends on natural conditions which are always changing and often face uncertainty, thereby affecting the condition of natural assets. Roslinda *et al*., (2024) continued that for human assets, the age and education of the head of the family greatly influence his behavior toward technology adoption and greatly determine workability and productivity (Roslinda *et al*., 2024). Younger farmers tend to be more innovative and open to new technology. Likewise, farmers with higher education tend to be more accepting and appreciative as well as implement innovations (Kongor *et al*., 2018).

Meanwhile, in Trenggalek, the results of the correlation analysis between livelihood assets and the technical efficiency of cocoa farming households are classified as moderate. This is because the livelihood assets of cocoa farming households are not fully utilized to achieve maximum production in cocoa farming, but also to undertake other activities, such as raising livestock (chickens and goats) and trading. Likewise, the high level of technical efficiency of cocoa farming does not necessarily mean that farmers can use it to increase the overall livelihood assets of farming households. This is because not all household livelihood assets can be increased by farmer household income, such as several indicators of natural assets and social assets which cannot be directly influenced by farmer household income.

Conclusions

This study aims to examine the level of livelihood of cocoa farming households, the technical efficiency of cocoa farming, and the relationship between the two in East Java. This research found that the livelihood assets of cocoa farmer households in both regions, Banyuwangi and Trenggalek

Regencies, were classified as moderate. Cocoa farming in Banyuwangi is not yet technically efficient, while in Trenggalek it is technically efficient. Furthermore, the linkage between livelihood assets and technical efficiency in Banyuwangi and Trenggalek has a positive correlation which is classified as weak and moderate. This proves that the higher the livelihood assets of cocoa farming households, the higher the technical efficiency of cocoa farming, and vice versa.

This study has limitations. This study did not analyze technical inefficiency factors that could influence TE. Further research needs to be carried out in this field, particularly by considering technical inefficiency factors and the possibility of significant differences in efficiency by farmers from different regions.

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Guest editorial

Knowledge and Information for a Sustainable and Innovative Agri-Food System: Insights from Research and Policy

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Across the globe, agri-food systems are under unprecedented pressure. Climate change, biodiversity loss, resource scarcity, market volatility, and rising social expectations for environmental and ethical responsibility are converging to create a new and complex operating environment for agriculture and food production. In all the World, the need for deep sustainability transitions is no longer a matter of debate, but rather an urgent imperative.

Yet, achieving a sustainable and innovative agri-food system is not solely a matter of introducing new technologies or setting environmental targets. It also requires reconfiguring how knowledge is produced, shared, and applied across the value chain, from research institutions and public authorities to farmers, food businesses, and consumers. In this regard, information quality, stakeholder learning, and participatory governance become as essential as technological innovation itself.

This special issue brings together three papers originally presented at the XXXII Conference of the Italian Society of Agri-Food Economics (SIEA) on "Knowledge and Information for a Sustainable and Innovative Agri-Food System" held in June 2024 in Ragusa (Sicily, IT). These contributions offer timely and complementary perspectives on the pivotal role of information in driving behavioral, market, and policy change in agriculture. They also reflect broader debates about how to align economic development, environmental stewardship, and social inclusion in the global food system.

The first article, "*Consumer's attitude in driving choices towards wine products derived from* ***New*** *Genomic Techniques (NGTs)*", addresses one of the most debated topics in agricultural biotechnology today: how to reconcile innovation with consumer trust. By examining the attitudes of Italian consumers toward wine produced using NGTs – advanced biotechnologies that promise greater crop resilience and reduced pesticide use – the authors provide empirical evidence on the critical role that accurate and accessible information plays in shaping public acceptance. The study's findings suggest that better-informed consumers are more open to innovation, particularly in light of potential regulatory reforms within the EU. But the implications go far beyond Europe: in a global context where misinformation and distrust can derail technological progress, this paper underscores the need for science communication strategies that are transparent, targeted, and sensitive to consumer concerns.

The second paper, "*The implementation of EU Optional Quality Term 'Mountain Products' in Italy*", explores how geographical labeling and place-based branding can support rural development and environmental sustainability. Focusing on the "Mountain Product" designation, the authors investigate why this EU Optional Quality Term (OQT), despite its potential to differentiate products and add value in marginal regions, remains underutilized. Through survey data from Italian producers, the study reveals a disconnect between the perceived benefits of the label and its actual market visibility, pointing to the need for more robust institutional support, marketing strategies, and consumer education. While the analysis is set in the European mountain context, the lessons are globally relevant: rural territories everywhere need better tools to capitalize on their unique ecological and cultural assets, especially in a globalized food system that often undervalues local identities and traditions.

The third article, "*Reconsidering EU Pesticide Policy to Address Sustainability*", tackles one of the most politically charged debates in agri-environmental governance: the future of synthetic pesticide use. Set against the backdrop of farmer protests and the European Commission's Strategic Dialogue on the Future of EU Agriculture, the paper examines how stakeholder input shaped the discourse on pesticide reduction. Through a qualitative analysis of official documents, the study demonstrates how deliberative governance processes can foster consensus around sustainability goals, while also revealing the structural, economic, and informational barriers that must be addressed for effective policy implementation. Although focused on the EU, this contribution speaks to a broader need for inclusive, knowledge-driven policymaking in agricultural transitions worldwide, particularly in balancing the trade-offs between ecological protection, food production, and rural livelihoods.

Together, these articles suggest that the informational infrastructure of agri-food systems is as important as their technological or financial components. Whether through biotechnology acceptance, quality certification uptake, or policy negotiation, what people know, how they learn it, and who controls knowledge access deeply influence the success or failure of sustainability transitions.

The articles in this special issue highlight a shared insight: without informed, empowered, and connected stakeholders, the sustainability transformation of agriculture will remain incomplete. Farmers require clear and actionable information to adopt new technologies. Consumers need transparent and trustworthy data to support sustainable purchasing choices. Policymakers must create platforms where diverse voices can shape the rules of the game.

The role of knowledge and information must be placed at the center of the debate.

Moreover, these contributions focus the attention to the global nature of agri-food challenges and the importance of localized, context-sensitive solutions. The dynamics of technology adoption, quality labeling, and pesticide regulation may vary across regions, but the underlying need for credible knowledge, participatory processes, and strategic communication is universal.

This special issue aims not only to disseminate the findings of these studies, but also to foster a broader reflection on the strategic role of knowledge and information in shaping the future of food systems. As the world moves toward increasingly ambitious sustainability goals, through frameworks like the EU Green Deal, the UN 2030 Agenda, and various national climate and food strategies, it becomes ever more crucial to invest in knowledge infrastructures that are inclusive, adaptive, and future-oriented.

This includes digital platforms for data sharing, open science initiatives, agricultural advisory systems, and inclusive spaces for dialogue between scientists, farmers, institutions, and consumers. In a context of misinformation, polarization, and fragmented governance, the capacity to build collective intelligence (i.e., a shared, plural, and reflexive understanding of agri-food challenges) is a public good of increasing strategic importance.

We hope the contributions in this issue will inspire further interdisciplinary research, policy innovation, and collaborative engagement between institutions, producers, and society at large. Only through shared understanding and informed cooperation can we truly redesign agri-food systems that are not only more productive, but also more just, resilient, and sustainable.

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The implementation of EU Optional Quality Term "Mountain Products" in Italy: Challenges and opportunities for the food sector in rural mountain areas

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Abstract

The Optional Quality Term (OQT) "Mountain Product" aims to promote mountain food products. This term can be beneficial for the economy of mountain regions, as it allows them to distinguish their products and can protect consumers from fraud, counterfeiting or agro-piracy. This study has two main objectives: to assess how farms that have adopted the label perceive their limitations and to analyse the reasons for these limitations and provide policy recommendations to strengthen the use of OQT. The study involves a survey of agri-food companies that have adopted the label, with data collected through a questionnaire. Although existing research indicates that consumers generally prefer mountain products and perceive them as higher quality, producers report that consumer awareness of the OQT is still low. It appears essential to improve communication with both producers and consumers on the economic, social and environmental benefits of the 'mountain product' label. Producers need support to integrate the label into their business strategies, while consumers should be informed about the ethical and social responsibility linked to the OQT.

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Introduction

Mountain areas cover 36% of the European surface area, host 13% of its population and 18% of farms (Euromontana, 2024), constituting an important resource reservoir for human activities (Bonadonna *et al*., 2022), ensuring the provision of ecosystem services and public goods for downstream areas (Moretti *et al*., 2023; Gupta *et al*., 2021) and, in general, of positive externalities (Bentivoglio *et al*., 2019a; McMorran *et al*., 2015).

Mountain agriculture contributes to the production of public goods and ecosystem services with small farms (Zuliani *et al*., 2018) that, compared to the lowland ones, present lower yields and a lack of economic sustainability (Mazzocchi *et al*., 2021a). The cause should be found in the environmental and climatic constraints of the mountain areas themselves (Zuliani *et al*., 2018; Tebby *et al*., 2010), which lead to higher production costs, as well as in the lack of a shared strategy and in structural barriers that hinder access to markets. In fact, in the 2014-2020 EAFRD programming, on which this contribution is focused, in the Regulation (EU) No 1305/2013, art. 32, it is said that mountain areas are characterised by "a considerable limitation of the possibilities for using the land and by a considerable increase in production costs, due to (a) the existence of very difficult climatic conditions due to altitude, resulting in a significantly shortened growing season; (b) the existence over the greater part of the territory of steep slopes making mechanisation impossible or requiring the use of very expensive special equipment, or a combination of the two factors". In addition to climatic and orographic specifics, mountain areas are increasingly subject to endogenous and exogenous threats, such as demographic dynamics and climate change (Scotti *et al*., 2023; Gupta *et al*., 2021; Wyss *et al*., 2022), which undermine their resilience. According to the recent report of the EU CAP Network (Competitive and resilient mountain areas, 2024), mountain areas are subject to a multiplicity of challenges, ranging from economics (high production costs and challenging conditions; lack of information and advisory services; barriers to access the agricultural markets; abandonment of agricultural activities; over-tourism), to social (ageing; education; lack

of specialised expertise), to environment (climate change; environmental degradation), and governance (lack of common and long-term strategy; infrastructures). Opportunities could be found in diversified incomes resulting from the development of new technologies in the field of ICT (Committee of the Regions, 2003). Furthermore, among the economic opportunities for mountain areas, the EU CAP Network report (2024) mentions mountain products (MPs), as their quality is being progressively recognised by consumers and their market share is growing, asserting that a stronger certification system could be an opportunity to strengthen consumers' trust.

In literature, there are many studies concerning the reaction of mountain communities to challenges and how they implement actions to strengthen their resilience (Ingty, 2017; Gupta *et al.*, 2021; Schneiderbauer *et al.*, 2021; Stotten *et al.*, 2021; Scotti *et al.*, 2023). Among these, a fair number of contributions (among others, Martins *et al.*, 2017; Mazzocchi *et al.*, 2021a; McMorran *et al.*, 2015) focuses on the opportunities offered by the Option Quality Term (OQT) Mountain Product designed by European Commission in 2012 adopting Regulation No. 11151/2012, and the Delegated Regulation No. 665/2014.

Although the OQT was established only in 2012, in 2005 Euromontana[1] presented to the European Parliament the European Charter for Mountain Quality Food Products, signed by 69 members from 12 European countries. The Charter focuses on promoting sustainable development in mountain areas regarding agriculture and food products and it is aimed at: a) Promoting the acknowledgment of the significance of developing mountain food products for both mountain regions and the entire European population; b) Specifying the fundamental principles that define mountain food products; c) Identifying the specific types of quality products that should be supported in their development; d) Determining the types of projects or initiatives that should receive support to further the objectives of the Charter (Euromontana, 2016). Finally, in 2012, the EU Commission settled out the so-called "Quality Package", whose aim is to overcome the market failure and reduce the risks of asymmetric information, creating food policies to protect the denomination of specific food products (Staffolani *et al.*, 2022; Mazzocchi *et al.*, 2021a). Among the "Quality Package", the EU Regulation No. 1151/2012 provides for the creation of the new optional Quality Terms "Mountain Product" and "Products from Island Farming", and the criteria for their use were then established in the Delegated Regulation 665/2014.

The OQT is aimed at agri-food products (milk and dairy products, eggs, meat products, honey, and plants, excluding spirit drinks, flavoured wines,

1. The European association for mountains.

or vine products), except for wine vinegars, due to the specific regulations and requirements governing these categories of products. According to EU Regulation 1151/2012, both raw materials and animal feed should come essentially from mountain areas. This regulation also sets the rules for the production processes of mountain products, specifying that they must take place within mountain areas, as referred to in Article 18(1) of Regulation (EC) No 1257/1999. According to Delegated Regulation 665/2014, Member States can adopt a derogation for the distance from mountain areas (maximum 30 km), that is, defining the number of kilometres of distance from areas considered to be 'mountain' in which the production of mountain products can take place. In addition, the Delegated Regulation calls on the Member States to monitor the use of OQT, set up a control scheme, define procedures for farmers, and allow them to adopt it. Furthermore, Member States can decide to design and use a national logo.

An Euromontana study on the implementation of the OQT (*Implementation of the EU Optional Quality Term "mountain product". Where do we stand in the different Member States?),* referring to the adoption of the OQT at national level, states that there are three types of Member States: the ones which are directly applying the EU regulation (Austria), the ones which are in the process of adapting their national laws to the EU regulation (France, Germany, Italy, Romania, Slovenia, Czech Republic, Bulgaria, Croatia) and those which have not yet adapted their national laws (Portugal, Spain, UK/Scotland, Greece, Cyprus, Slovakia, Poland, Finland and Sweden) (Euromontana, 2020).

This paper focuses on the second group, analysing and interpreting the Italian case, to understand how European regulations have been adapted and how it deals with the term through the adoption of rules and derogations relating to its use, as well as the control and support system provided. This contribution, therefore, aims to pursue three specific objectives: a) to explore the perception of the limits of the term experimented by farmers and producers that have adopted it; b) to analyse the limitations regarding the diffusion and/or implementation of OQT, and c) to analyse the causes of these limits to provide useful policy guidelines to strengthen the adoption of OQT by mountains operators (farmers and processors) by enhancing mountain products exploiting their potential for mountain economies. To this end, the paper proposes an analysis of the literature on the certification of mountain products, followed by a focus on Italian legislation, since, as specified above, the proposed case study concerns the Italian situation. The Materials and Methods section presents the methods of the survey conducted on the universe of Italian firms using OQT. Then, a multinomial (logistic) regression analysis was carried out to focus on the limits in the implementation of OQT. The analysis revealed, above all, territorial and sectoral limits and/or

differences, which has suggested a repositioning or new orientations of the policies aimed at enhancing the value of mountain products.

1. Background

Analysing academic literature, the interest in the mountain product term, although begins to grow, it would still seem to neglect this important form of product differentiation, perhaps also due to the refractoriness shown by mountain farmers and food processors and/or due to delays in implementing the regulation by most member countries.

There is instead wide evidence in the literature that the economy of mountain areas can benefit from the introduction of OQT (Zanchini *et al.*, 2023; Mazzochi *et al.*, 2021a; Martins *et al.*, 2017). This brings benefits both in business terms, which are directly reflected in the territory and its economy, and in terms of consumption.

The adoption of the mountain term can protect consumers from fraud, counterfeiting or agropiracy (Cagnina *et al.*, 2018), supporting the local economies of rural mountain communities (Bonadonna *et al.*, 2017), and protecting also the uniqueness related to the areas of origin, traditional knowledge and practices they embed (Bassi *et al.*, 2022; Bonadonna *et al.*, 2015; Zanchini *et al.*, 2023). The increase and consolidation of the demand for mountain products can therefore contribute significantly to the reduction of unemployment in those areas, stemming the phenomena of depopulation, exacerbated by youth migration, to the extent that the unexpressed market potential of mountain products can be unlocked through the OQT, which could increase the added value generated by farms (Staffolani *et al.*, 2022; Mazzocchi *et al.*, 2021b; Martins *et al.*, 2017; Zuliani *et al.*, 2018).

The maintenance of mountain agriculture and entrepreneurship would allow the production of ecosystem services, of which lowland communities can also benefit. At the same time, the promotion of the OQT and the subsequent increase in demand can mainly lead to two types of consequences for the territory. The first one is related to the benefits that the label could bring: an improved demand for mountain food products could support and incentive farmers and producers and contribute to the development of the areas, ensuring local production and delivery of mountain foodstuffs (Zanchini *et al.*, 2023; Mazzochi *et al.*, 2021a; Martins *et al.*, 2017). The second one, instead, is related to the risk that a huge increase can negatively affect natural resources, for example, through intensive management of grassland.

Looking at them from the consumer side, mountain products have specific characteristics that make them attractive for consumers, who perceive their

quality and are willing to pay for it. In the common imagination, mountain regions are linked to positive images of green valleys, clear waters, purity, authenticity, unspoiled nature, and well-being (McMorran *et al.*, 2015; Stiletto *et al.*, 2023; Mazzocchi *et al.*, 2021a). These characteristics are also included in foodstuffs produced in these areas, which, from the consumers' view, gain attribute 'quality'. Hence, consumers appreciate the mountain product as it represents all the elements they desire in mountain food products: taste, nutritional excellence, safety, attractive flavours, diversity, and high-quality ingredients. Moreover, it captures their personal motivations and positive associations linked to consuming mountain foods, including health benefits and enjoyable aspects (Bassi *et al.*, 2021). Furthermore, the mountain product is perceived as "place embedded", as it is easier to purchase in local artisan shops and mountain farms than in speciality shops and urban supermarkets. When assessing consumers' willingness to pay for mountain products, it emerged that consumers are effectively willing to pay a premium price for such products, the purchase of which is influenced by a series of variables (Bonadonna *et al.*, 2016; Zanchinj *et al.*, 2023) such as, for example, the sensory and organoleptic characteristics of the products, the mood and positive thoughts associated with the mountain as a place of production (Staffolani *et al.*, 2022; Bonadonna *et al.*, 2016), as well as the attention to animal welfare and the territorial valorisation (Mazzocchi *et al.*, 2021a).

A crucial role is also played by mountain agriculture, which, although exposed to higher costs due to the extreme conditions, guarantees a high-quality finished product, thanks also to processing methods and certain physical characteristics of the area. Despite the challenges, mountain agriculture is still able to penetrate niche markets (as mountain products are considered to be) and short supply chains (Oostindië *et al.*, 2010; De Rubertis *et al.*, 2024; Bonadonna *et al.*, 2022), bringing higher profit margins for producers and contributing to the development of the region (Zanchini et al, 2023).

Despite the positive aspects and benefits that mountain products can bring to mountain areas and consumers, the term shows some weaknesses. The main ones are related to the lack of communication of the label and to its improper use. In some cases, products are marketed as 'mountain' that do not comply with EU legislation in this regard, taking advantage of the positive image of mountain areas and all their characteristics. This can lead to adverse selection risks, which devalue authentically mountainous products and value those obtained from less extreme areas, reducing the potential market advantage of mountain products (Akerlof, 1970). In most surveys conducted, farmers complain that even if consumers perceive a positive image of mountain products (Bonadonna *et al.*, 2017; Mazzocchi *et al.*, 2021a), there is a low level of knowledge about the OQT and the

characteristics of products (Bentivoglio *et al.*, 2019b). To overcome the problem and exploit the label's potential, it should be communicated in a widespread manner, aiming at fostering consumers' awareness. On the other hand, institutions can act strengthening the importance of the origin of agri-food products in the collective imagination (Bonadonna *et al.*, 2022). In addition, it emerges that the derogation to a maximum distance limit of 30 km for transformation phases constitutes a weakness for the mountain products, as it allows transformation outside the mountain area (Bonadonna *et al.*, 2017): this is not in line with most producers' philosophy, according to which all activities must be carried out in mountain areas. These differences lead one to consider the OQT as an excellent alternative in policies of qualification and strategic differentiation of agro-alimentary products where other quality certifications are not available or in cases where they do not effectively reflect the specific characteristics of the territory, as in the case of Caciocavallo cheese in some Apennines regions (Moretti *et al.*, 2023).

1.1. *The Optional Quality Term Mountain Product in Italy*

In Italy, EU Regulation 1152/2012 has been implemented by Decree of the Ministry of Agriculture, Food and Forestry (now Ministry of Agriculture, Food Sovereignty and Forestry) No. 57167/2017, through which the EU Regulation has been adapted to national law and conditions of the use of the OQT, derogations, the national logo (Figure 1) and control schemes have been established. Subsequently, with the adoption of the Ministerial Decree of 20 July 2018, guidelines for animal feeding and conditions for the use of logos were established.

Figure 1 - Italian logo for OQT 'mountain product'

Source: Ministry of Agriculture, Food Sovereignty and Forests.

Italy has established a 30 km derogation for all activities outlined in Delegated Regulation; with regard to controls, it is established that producers are controlled only after they started to use the OQT (by the Department of Central Inspection for the Protection of Quality and Suppression of Fraud in agri-food products or ICQRF), and they have to ensure the traceability of both raw materials and animal feed used. Monitoring and control are assigned to the Regions, which are responsible for the authorisation for use. Producers must apply for authorisation to use the OQT by filling out a form with the region in which they intend to carry out their activity. Then, each Region should fill and update a list of producers using the OQT and send it to the Ministry every six months, to be published on the official website (Scaglioni *et al*., 2024).

2. Materials and Methods

Data collection of this work is to be included in the framework of the Horizon 2020 project Mountain Valorisation Through Interconnectedness And Green Growth project (MOVING), in particular in the analysis that AREPO (Association des régions européennes des produits d'origine), in collaboration with Euromontana and Highclere Consulting (HCC), carried out on the implementation of the EU OQT 'mountain product' (Scaglioni *et al*., 2024). The survey has been carried out through the administration of a questionnaire in Italy, Romania and France, but significant responses were only obtained from Italy and Romania, as both have regional (Italy) and national (Romania) databases through which a list of producers to contact can be traced. In France, on the other hand, having no register or list, it was almost impossible to contact the operators.

To achieve the research objectives, this paper refers to the Italian situation, so it exclusively takes into account the replies recorded for Italian producers.

The questionnaire is divided into five main sections:

A. Contact details, aimed at obtaining information on the location (region) of the producers.
B. Data on registered users, aimed at obtaining information on the type of activity, number of animals, UAA and product categories, as well as on the use of quality schemes and the value of production.
C. Knowledge of the OQT 'mountain product' aimed at investigating knowledge and motivation to join the scheme.
D. Access to the scheme, aimed at evaluating any kind of costs, controls and assistance.
E. Evaluation of the practice. In this section, operators were asked what the major obstacles were in the promotion and distribution of mountain

products and to provide recommendations on how to improve these aspects. Among others, they were asked what could be improved in general about the OQT, whether it is necessary to proceed with the promotion of mountain products through territorial promotion policies and, finally, to provide suggestions to the public administration. The answers to these questions were open-ended and optional, and so it was possible to create clusters into which these answers could be merged.

Therefore, the survey was conducted on the universe of Italian agri-food business that have adopted the OQT and are enrolled in the regional registers managed by MASAF (Italian Ministry of Agriculture, Food Sovereignty and Forestry). The questionnaire, which included both multiple-choice questions and open-ended answers, made it possible, on the one hand, to collect information about the structure of the farms involved, the type of production, etc., and, on the other hand, to give farmers and producers the opportunity to express their opinion on the subject.

Producers were reached by certified e-mail in April and May 2023. The questionnaire was sent to the whole list of producers, amounting to 1202, but it was completed by only 150 of them, corresponding to an acceptable coverage of 10% of the universe surveyed.

The data were first analysed through a descriptive analysis, aimed at investigating the location of the companies, the type of production and product, and the volume of production and revenue obtained with the OQT. The first qualitative analysis conducted, even if it allows the achievement of the established objectives, shows its limits, which can be seen, for example, in the interpretation of the producers' answers (difficulty in creating clusters based on open answers) or in the absence of specific quantitative data relating to mountain agriculture. This led to the choice of a quantitative statistical analysis to understand the limitations experienced by the operators (section E of the questionnaire) and the dependence of these limits on a series of variables and conditions investigated in the questionnaire. To this aim, a multinomial regression model with a polytomous response variable was used (Agresti, 2013).

The model allows the assessment of the probability that a specific variable causes a specific limit to appear. In this regard, 4 classes of limits are organised after the first descriptive analysis (1. costs and logistics; 2. low product valorisation; 3. poor brand recognition by consumers; 4. weak communication and promotion by Public Administrations). The independent variables considered are listed in Table 1 below and deal with the geographical area where the business is located, type of activity, membership of Geographical Indications, type of product, value and percentage of production obtained using the OQT.

Table 1 - Variables and characters

Variables	Characters
Geographical area[2]	South & Islands
	Centre
	North-west
	North-east
Type of activity	Primary production
	In-farm processing
	Off-farm processing
Adhesion to a GI	Yes
	No
Product category	Fresh meat and meat products
	Milk, cheese and other dairy products
	Other products of animal origin
	Fruit, vegetables and cereals, fresh or processed
	Honey and other bee products
	Bread, pastry, cakes, confectionery, biscuits and other bakery products
	Fresh fish and fish products
	Other
Value of production using the OQT	0-10.000€
	11.000-20.000€
	21.000-30.000€
	31.000-40.000€
	41.000-50.000€
	51.000-60.000€
	61.000-70.000€
	71.000-80.000€
	81.000-90.000€
	91.000-100.000€
	>100.000€
Share of production obtained using the OQT	Integral (100%)
	Relevant (99-50%)
	Partial (<50%)

Source: Own elaboration.

2. South & Islands: Abruzzo, Molise, Campania, Puglia, Basilicata, Calabria, Sicilia, Sardegna. Centre: Toscana, Umbria, Marche, Lazio. North-west: Piemonte, Valle d'Aosta, Lombardia, Liguria. North-east: Autonomous Provinces (P.A.) of Trento and Bolzano, Veneto, Friuli Venezia Giulia, Emilia Romagna.

3. Results

The results were first analysed about the number of holdings in a given territory, the type of production and the profits from the use of the OQT, in an attempt to understand the farmers' and producers' actual possibility of deriving greater value from their production through its use.

According to the database available on the Ministry website, in Italy there are (early 2023) 1202 farms using the OQT (Table 2), allocated in 16 out of 20 regions (surprisingly, it is not used in Molise, Campania and Umbria, but also in Puglia).

Table 2 - Regional distribution of OQT adoption

	Farms and processing companies using the OQT	Completed questionnaires returned	Survey coverage
Piemonte	462	58	12,55%
Basilicata	181	5	2,76%
Emilia-Romagna	142	22	15,49%
Abruzzo	80	4	5,00%
Lombardia	77	15	19,48%
Friuli-Venezia Giulia	72	7	9,72%
Veneto	60	10	16,67%
Toscana	52	8	15,38%
Valle d'Aosta	18	7	38,89%
P.A. Trento	13	4	30,77%
Sardegna	10	3	30,00%
Calabria	9	2	22,22%
Marche	6	1	16,67%
Sicilia	6	1	16,67%
Lazio	5	0	0,00%
Liguria	5	3	60,00%
P.A. Bolzano	4	–	–
Campania	–	–	–
Molise	–	–	–
Puglia	–	–	–
Umbria	–	–	–
	1202	150	12,48%

Source: MASAF, ISTAT, and own elaboration.

The Region with the highest number of farms using the OQT among the total number of farms is Piemonte, with a percentage of 0.98%, followed by Valle d'Aosta (0.73%). While for Valle d'Aosta this percentage is explained by the small number of farms in the region, for Piemonte region a higher incidence is observed, due, on the one hand, to the size of the mountain territory, which covers more than 40% of the entire surface area, and, on the other, to the measures and initiatives promoted by the Region. Indeed, with its 2014-2020 Rural Development Program (RDP), Piemonte has sought to favour, to qualify its mountain productions, the diffusion and use of the mountain product indication by providing a series of bonuses for the use of the OQT. Specifically, these are Measure 4 - Investments, Sub-measure 4.1 - Support for investments in agricultural holdings and Measure 6 - Young diversification, Sub-measure 6.1 - Start-up premiums for young farmers. It should also be noted that the same farm can apply for the use of OQT for more than one production chain (Bonadonna *et al.*, 2020). The specific attention paid by Piemonte to the differentiation of mountain agri-food products, although the incidence of mountain territory is significantly lower than that of other regions (such as Molise and Umbria), denotes a broader and more inclusive vision, more attentive to the strategic potential of rural mountain areas whose development cannot but be centered on the valorisation of agri-food production through product differentiation strategies.

To assess the strategic value attributed by the companies to the OQT, the sample has been stratified based on the following three variables:

1. Ranges of revenues obtained from production with the OQT (Table 3);
2. Type of production (primary production, on-farm processing, off-farm processing);
3. Percentage of production itself obtained using the OQT (integral = 100% of production using OQT; relevant = 99-51% of production using OQT; partial = <50% of production using OQT).

A preliminary descriptive analysis was therefore conducted by considering the variables simultaneously:

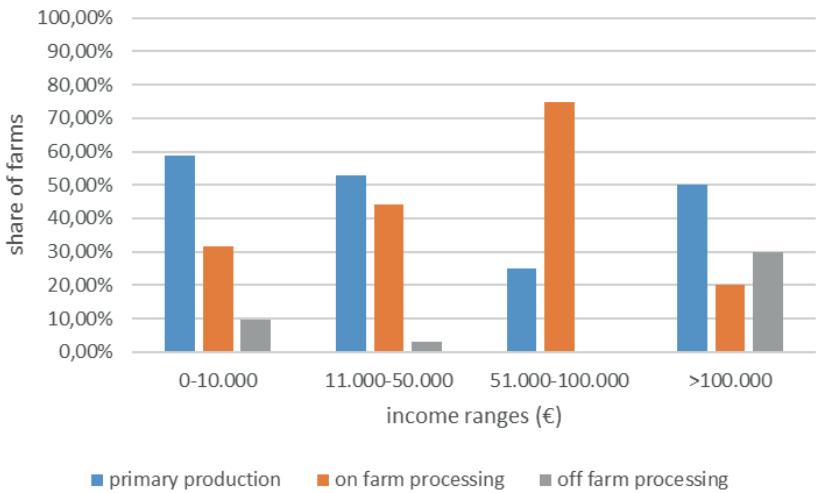
- Type of production and income ranges (Figure 2);
- Income ranges based on the percentage of production obtained using the OQT and divided by type of production (Figure 3).

Table 3 - Percentage of farms that use OQT by income range obtained from it

Revenue Ranges (€)	Share of Farms
0-10.000	56,76%
11.000-50.000	30,63%
51.000-100.000	3,60%
>100.000	9,01%

Source: Own elaboration.

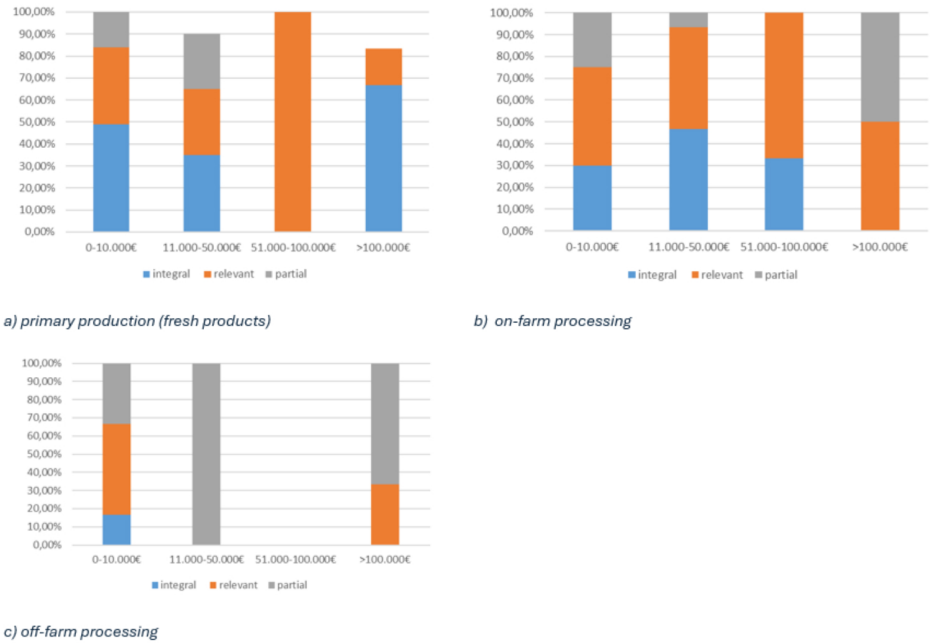
Figure 2 - Type of production by income ranges



Source: Own elaboration.

A strong polarization of farms (56,76%) in the 0-10,000 € band can be seen in Table 3 and Figure 2. Concerning the production type, on the other hand, 59% of the businesses in the first revenue band are engaged exclusively in primary activities, while the remaining 40% are in processing activities. Such distribution is also surprisingly confirmed for companies belonging to the higher revenue classes, with 52,94% of companies in the € 11,000-50,000 range and 50% of those with over € 100,000 in turnover, thus registering an apparent greater rigidity of processors to the adoption of the OQT. Despite the higher value of processed products, the difference could be attributable to both the greater organisational complexity of the processors and their lower presence in the sample and the MASAF lists.

Figure 3 - Revenue classes obtained using OQT analysed by type of production



Source: Own elaboration.

In Figure 3, for each type of production activity (primary production, on-farm processing and off-farm processing), the type of production (full, relevant or partial, according to the percentage obtained with OQT) is related to the level of income from the same production as OQT.

Concerning primary production, it is observed that as income increases, the share of farms with partial production decreases. In the case of on-farm processing, as income increases, the number of holdings with a significant share (between 51% and 99%) of TQO production increases, while the share of holdings with full TQO production decreases. For off-farm processing, there is greater heterogeneity between the different income brackets. Overall, what emerges from Figure 3 is a general tendency for the share of production with OQT to decrease as income increases.

Because of the low percentage of farms using the OQT (Table 2) and given the relative procedural simplicity of using it and the apparent lower costs compared to other forms of quality certification, as well as a whole series of benefits for producers and mountain territories, the question of its low use was raised. To this end, the answers given by the farmers and processors in

the second part of the questionnaire, aimed at investigating the limitations of using the OQT itself, were analysed.

The limitations of the application and use of the OQT were investigated both in terms of costs incurred by producers (Table 4 below) and in terms of communication with final consumers and public administrations (sections D and E of the questionnaire). Despite the opportunity of the low costs related to the term adoption, there is still a percentage of farmers who consider the practice expensive, in fact 15% of respondents still claim to have incurred higher costs in connection with the implementation of the OQT, most of which can be found in administrative and control costs. These types of costs could refer to the traceability requirements that, according to Ministerial Decree 57167/2017, must be ensured at every stage of production, processing and marketing.

Table 4 - Interpretation of higher costs of OQT

Costs categories	**% Responses (more than one answer was possible)**
Administrative costs	50%
Control costs	32%
Adaptation of production processes	27%
Adaptation of company structures	9%

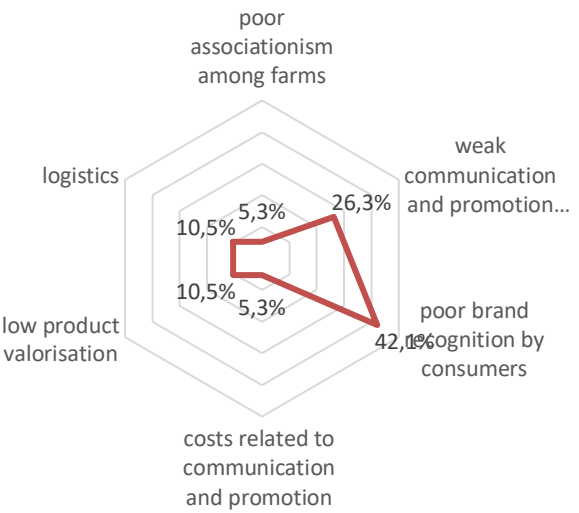
Source: Own elaboration.

As shown in Figure 4 below, the most frequently appearing obstacle is the lack of brand recognition by the consumer, associated with low consumer awareness. In addition, producers complain about the lack of brand promotion, the effect of which can be seen precisely in the lack of consumers' awareness and brand recognition.

The major limitations complained of by producers are to be found in the lack of knowledge of the OQT caused by insufficient information and/or misinformation (both of consumers and the producers themselves). Moreover, other producers complain about the limited tourist visibility of some mountain territories, accompanied by an insufficient institutional promotion of the 'Mountain Product' brand, as well as by the lack of technical support to companies in the design/adoption phase of the OQT. Most producers also denounced greater competitiveness of lower quality products, whose origin is consciously misrepresented by producers and/or distributors with little transparency, as well as the absence of alternative markets capable of

intercepting and distributing these products in selected circuits, and prices that are still scarcely remunerative.

Figure 4 - Main limits regarding promotion and distribution (marketing) of mountain products



Source: Own elaboration.

Many operators, to overcome the lacks mentioned above, are being faced with higher advertising and promotion costs. Consequently, a key role is played by the public administration, whose lack of support is lamented by producers. Finally, logistics, due to the conditions of mountain areas, seems to be an obstacle to the distribution of mountain products in markets far from their area. The recommendations provided to improve the promotion and distribution of mountain product all converge in the direction of enhancing and improving promotion: in fact, producers suggest a series of measures, ranging from TV advertising spots, to the organization of dedicated fairs and events, to massive information campaigns, to the creation of a specific website that brings together all products (as of today, there is only a list of companies adopting OQT for each region on the Ministry website). 77% of respondents agree that it would be appropriate to encourage adherence to the scheme of the OQT through territorial promotional policies; 80% of them agree that territorial promotional policies should include promotional campaigns, local market events, advertising and so on.

The limitations encountered by operators in the application of OQT were therefore subjected to further statistical analysis, through a multinomial regression model, as described in the Materials and Methods Section.

In doing so, the six limits identified in Figure 4 (1. Poor associationism among farms; 2. Weak communication and promotion by Public Administrations; 3. Poor brand recognition by consumers; 4. Costs related to communication and promotion; 5. Low product valorisation; 6. Logistics) have been grouped into four categories to streamline the analysis (1.costs and logistics (4;6); 2.low product valorisation; 3.poor brand recognition by consumers; 4.weak communication and promotion by Public Administrations).

Multinomial (logistic) regression allowed us to verify and evaluate the impact of specific variables on certain limitations. The results can be found in Table 5 below, in which only significant variables (p value < 0,1) are reported for the sake of brevity (see Appendix for the complete output of the model in Table 7). The model is estimated through the *VGAM* package in R Studio (see, e.g., Yee, 2010), and we also present the average marginal effects (computed through the 150 observations) alongside the usual estimates of the relative log-odds. The complete table of averaged marginal effects is depicted in the Appendix (Table 8).

Table 5 - Multinomial regression model

Variable	Estimate	Average marginal effect	Std. Error	z value	p value
Area North-East:4	–2,930	–0,284	1,467	–1,994	0,04574 (*)
Activity_primary production:2	–2,121	–0,136	1,212	–1,749	0,08021 (°)
Activity_primary production:3	–1,852	–0,198	0,935	–1,980	0,04767 (*)
Adhesion_PDO_ PGI_other: Yes:4	1,278	0,144	0,700	1,826	0,06782 (°)
Product.categoryE:4	2,324	–0,375	1,397	1,664	0,09618 (°)
Product.categoryF:4	4,695	0,691	2,268	2,070	0,03844 (*)
PERC:2	0,020	0,001	0,100	2,103	0,03549 (*)
PERC:3	0,013	0,001	0,007	1,871	0,06130 (°)

Source: Own elaboration.
"°": p-value <0,1; "*": p-value <0,05.
(For Product.categoryE:4: This relationship is the weakest: in fact, the coefficient is positive but the average marginal effect is negative. The p-value is approximately 0.1, which could explain the existence of the limit).

Table 5 shows how the possible limits are related to five significant variables (1. Geographical area, 2. Type of activity (primary production), 3. Adhesion to PDO and/or PGI, 4. Product category (E = honey and other beehive products; F = bread, pastries, cakes, sweets, biscuits and other baked goods), 5. Percentage of production realized using the OQT. The number following the name of the variable indicates the probability of the variable identifying the limit associated with that specific number. For instance, Area North-East:4 means that we are going to investigate the probability that the variable Area: North-East identifies limit 4, i.e. weak communication and promotion by Public Administrations.

Table 6 - Significant variables for the occurrence of the limits considered

Variables/Limits	**1. costs and logistics**	**2. low products valorisation**	**3. poor brand recognition**	**4. weak communication and promotion by PA**
Adhesion to PDO and/or PGI				X
Product category: honey and other beehive products				X
Product category: bread, pastries, cakes, sweets, biscuits and other baked goods				X
Percentage of production using the OQT		X	X	

Source: Own elaboration.

As shown in Table 6, which offers a summary of results obtained through the multinomial regression. Observing the data reported in Tables 5 and 6, a lower propensity (recognisable in the negative sign of the estimate) to encounter limits 2 (low product valorisation), 3 (poor brand recognition) and 4 (weak communication and promotion by PA) respectively in the case of primary production activities and in the case of location of the companies in north-eastern Italy can be seen.

The limitations of 'low product valorisation' and 'poor brand recognition' seem to be experienced less by those who carry out primary activities using OQT and by those who produce high quantities using the same OQT.

The "weak communication and promotion by Public Administration" limit is also related to the type of product, specifically "honey and other beehive products" and "bread, pastries, cakes, sweets, biscuits and other baked goods". This limit is also associated with the variable "membership of PDO and PGI schemes", as well as with the higher percentage of production using the OQT.

4. Discussion

The first evidence that emerges from the survey is the low correlation between the mountainous areas of some regions and the number of operators using OQT (Table 2). This phenomenon, although more evident in southern Italy, is also widespread in the north. In the south, in fact, except for Basilicata (which has 181 users of the OQT), the rest of the regions, even those with extensive mountainous areas (such as Molise and Campania), count very few, if any, users.

Moreover, even when observing the number of farms using the OQT in the north, as for example, Valle d'Aosta and the autonomous provinces of Trento and Bolzano, it emerges that even if these are regions with 100% mountainous territory, they have very low numbers in relation to the use of the OQT.

Specifically, the limitation regarding the role of the public administration in promoting the term is less likely to occur if the operator user is located in the north-east geographical area, probably because the policies adopted by the Regions (RDP) belonging to that area contain more specific measures. As stated in the AREPO report (Scaglioni *et al.*, 2024), the regions of the north-east (Veneto, Emilia-Romagna, Friuli-Venezia Giulia) have made available on their website a page entirely dedicated to mountain products, providing practical information on how to use them, as well as explanatory videos and brochures. Moreover, as can be seen from Table 7 in the Appendix, the variable Geographical area: north-west, although with a non-significant p-value, also shows a negative sign about the occurrence of all 4 limits investigated, which is not the case for the variable Geographical area: south and islands, thus marking the difference between north and south.

According to AREPO (Scaglioni *et al.*, 2024), especially in the north, this can be attributed to the presence of other regional-type labels and/or claims that are more recognised by consumers and receive more support from local administrations. Indeed, some studies (Stiletto *et al.*, 2023; McMorran *et al.*, 2015; Menozzi *et al.*, 2022) have found that the presence of multiple labels related to the product's provenance (e.g. mountain product + PDO) can be confusing to consumers, who are willing to pay less for quality attributes.

At the same time, the presence of multiple labels leads to higher costs for producers, who might benefit from using fewer quality terms (Stiletto *et al.*, 2023).

The second category of limits relates, on the one hand, to consumer information and awareness (poor brand recognition) and, on the other, to the low product valorisation due to poor communication and/or support in promoting it. Producers highlight key issues, including insufficient knowledge of OQT due to limited tourist visibility in some mountain areas, weak promotion of the 'Mountain Product' term, and lack of technical support. They also face unfair competition from misrepresented lower-quality products, limited market access, and unprofitable pricing. This evidence suggests a lack of attention and/or a progressive threat of disaffection to the OQT caused by the sub-optimal value that the conventional market continues to recognise to these products, justifying the scarce recourse to the instrument especially by processors.

However, as shown in Table 5, there are some limitations that are less likely to occur if associated with a particular variable.

The variable type of activity, regarding primary production, has a negative sign and, therefore, a low probability of reaching the limit related to poor communication and promotion of the public administration: the farmer, upstream in the chain, may not have direct contact with the final consumer and, therefore, not receive feedback on the products. At the same time, he may also not receive feedback from the intermediaries in the chain or the processors and thus does not really perceive the issue.

Furthermore, there is a tendency to be less critical of the limitations related to the low valorisation of the product and the low degree of recognition of the OQT by the consumer when the product in question comes from primary production. Primary production considering the distance that generally separates them from the consumer, unlike production on and off the farm, allows natural characteristics to be preserved, and direct traceability ensures its origin (Bentivoglio *et al.*, 2020; Martins *et al.*, 2017; Bentivoglio *et al.*, 2019b).

While the literature shows that the average consumer expresses a preference for mountain products, recognising in them attributes of higher quality, operators complain of a lack of consumers' awareness of OQT (Bentivoglio *et al.*, 2019b; Bassi *et al.*, 2021). The literature review revealed a lack of communication and promotion of the OQT (McMorran *et al.*, 2015; Stiletto *et al.*, 2023; Martins *et al.*, 2017; Bonadonna *et al.*, 2017), which was empirically found in the questionnaire: consumers recognise the quality of the mountain product itself, but not the scheme, as they are not familiar with the OQT logo and, as a result, they are unaware of the rules underlying the adoption of the OQT itself and the requirements that raw materials

and production must meet for the product to be considered "mountain". According to AREPO (Scaglioni *et al*., 2024), this challenge extends its impact throughout the entire supply chain, exacerbating the competition with lower-quality products. Thus, if consumers show a certain willingness to pay for products for which they recognize the mountain origin and all the qualities and peculiarities that come with it, but if they are unable to recognize the OQT logo, they may not show the same willingness to pay because they do not understand the message of food safety and guarantee that is underlying the OQT itself (Stiletto *et al*., 2023; Bonadonna *et al*., 2022; Bentivoglio *et al*., 2020).

The limitation related to the lack of support from the public administration appears to be related to the simultaneous adoption of geographical indications, such as PDO and PGI. In fact, in this regard, from scientific literature it emerges that (Menozzi *et al*., 2022; Stiletto and Trestini, 2023) the OQT has no negative overlap with the Organic label, as they are intended to provide different information. The consumer is willing to pay a certain premium price. His willingness to pay, on the other hand, decreases when a third label, the PDO label, is added to these two labels. With this label, production costs increase, which also leads to an increase in the final price of the product, which, however, is not recognised by the consumer.

Another variable that leads to the finding of the limit related to communication and support from the public administration is that related to the category of bee products. Mountain beekeeping is a niche sector, often practiced by small family-owned producers with limited production and representing a small percentage of total Italian agricultural production. This is compounded by a weakness in the construction of a strong narrative around these products.

Conclusions

The study proposed an analysis of producers' and processors' points of view on the OQT. Results show a territorial disparity between northern and southern Italy in terms of support from Public Administrations: the north, as also witnessed by AREPO (Scaglioni *et al*., 2024), regional administrations (Emilia-Romagna, Piemonte, Veneto, Lombardia, Friuli Venezia Giulia) implement communication and/or promotion policies for the OQT. The significant differences highlighted indicate that public intervention can play a decisive role in promoting OQT, both for producers and consumers, enabling greater awareness and knowledge, even if operators do not complain of excessive costs or obligations and recognise the value and potential of the OQT use in terms of competitive advantage. However, they

complain of a lack of logo-consumer communication: consumers recognise the product from mountain areas as being of quality and different from other products, but find it difficult to associate the logo with it. It is therefore crucial to enhance information to both producers and consumers on the economic, social and ecological potential of the Mountain Product label. While operators will have to be accompanied, above all, in the phase of integrating the mountain label into business strategies, consumers will have to be informed about the ethical and social responsibility implications of the OQT. Only a more effective flow of information will make the market more transparent, adding value to mountain products and stimulating the construction of new relationships between farmers and processors, capable of increasing the resilience of mountain economies and helping to stem the devastating depopulation phenomenon.

Since one of the purposes of this study is to offer guidelines to policy makers for a greater valorisation of mountain products, it was found that, in its report, AREPO (Scaglioni *et al.*, 2024) provides a list of policy recommendations at EU, national, regional and local levels. At EU level, it is asked to policy makers to design specific measures for mountain products, as well as to deploy promotion strategies and encourage member states to include mountain product legislation in their own legislation. At the national level, there are always calls for action on initiatives to promote OQT and, in addition, on controls to prevent its inappropriate use. Member States are also asked to re-evaluate the derogations granted, as they themselves can be causes of competition between actors operating in the mountains and those who take advantage of the derogations to operate outside those areas (Fernández-Barcala, 2016; Messer *et al.*, 2008). The theme of promotion is present at the local level, and it is here that the need for local policies converges exclusively on this theme, outlining the need for the provision of promotional materials, the organization of dedicated fairs and events, as well as dedicated spaces within local markets (Casati, 2006; Canavari *et al.*, 2010).

Nevertheless, results are in line with the very recent EU CAP Network report (2024), in which research needs about marketing for mountain products and willingness to pay for them emerge. It is recognised that producers do not have the necessary skills and knowledge to understand the behaviour of consumers who, at the same time, are unable to recognize the value of OQT. Therefore, policy and decision makers should grant producers of appropriate tools to understand these phenomena by transferring research results to them and providing them with training in communication and marketing. At the same time, specific policies should be designed also for consumers, enhancing targeted promotion campaigns and other initiatives aimed at boosting their awareness.

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Appendix

Table 7 - Full Output of the Multinomial Regression Model

Variables	Estimate	Std. Error	z value	p value
(Intercept):1	–17,102	1734,813	–0,010	0,9921
(Intercept):2	–0,492	1,779	–0,277	0,7820
(Intercept):3	–17,405	1655,028	–0,011	0,9916
(Intercept):4	–1,720	1,616	–1,065	0,2871
Area South & Islands:1	–0,903	1,668	–0,541	0,5882
Area South & Islands:2	–0,745	1,737	–0,429	0,6680
Area South & Islands:3	0,572	1,285	0,445	0,6562
Area South & Islands:4	–0,381	1,284	–0,296	0,7669
Area North-East:1	–0,112	1,304	–0,086	0,9318
Area North-East:2	0,931	1,403	–0,664	0,5068
Area North-East:3	–0,257	1,111	–0,231	0,8172
Area North-East:4	–2,930	1,467	–1,998	0,0457
Area North-West:1	–1,444	1,345	–1,074	0,2827
Area North-West:2	–0,591	1,345	–0,439	0,6604
Area North-West:3	–0,273	1,092	–0,250	0,8027
Area North-West:4	–0,604	1,086	–0,556	0,5783
Activity_on farm processing:1	1,013	1,354	0,748	0,4544
Activity_on farm processing:2	–1,958	1,249	–1,568	0,1168
Activity_on farm processing:3	–1,154	0,977	–1,181	0,2377
Activity_on farm processing:4	–0,224	1,033	–0,217	0,8281
Activity_primary production:1	0,140	1,318	0,107	0,9152
Activity_primary production:2	–2,121	1,213	–1,749	0,0802
Activity_primary production:3	–1,852	0,935	–1,980	0,0477
Activity_primary production:4	–1,020	0,968	–1,054	0,2917
adhesion_PDO_PGI_other:Yes:1	0,232	0,835	0,278	0,7808
adhesion_PDO_PGI_other:Yes:2	–0,624	0,922	–0,676	0,4989
adhesion_PDO_PGI_other:Yes:3	–0,202	0,685	–0,294	0,7684
adhesion_PDO_PGI_other:Yes:4	1,278	0,700	1,826	0,0678
product.categoryB:1	16,272	1734,812	0,009	0,9925
product.categoryB:2	0,304	1,376	0,221	0,8251
product.categoryB:3	16,603	1655,027	0,010	0,9920

Variables	Estimate	Std. Error	z value	p value
product.categoryB:4	1,471	1,343	1,095	0,2734
product.categoryC:1	16,015	1734,812	0,009	0,9926
product.categoryC:2	1,914	1,405	1,362	0,1732
product.categoryC:3	17,931	1655,027	0,011	0,9914
product.categoryC:4	2,110	1,397	1,511	0,1308
product.categoryD:1	15,885	1734,812	0,009	0,9927
product.categoryD:2	–0,454	1,361	–0,333	0,7389
product.categoryD:3	17,014	1655,027	0,010	0,9918
product.categoryD:4	0,902	1,302	0,693	0,4885
product.categoryE:1	16,450	1734,812	0,009	0,9924
product.categoryE:2	1,083	1,426	0,759	0,4477
product.categoryE:3	17,626	1655,027	0,011	0,9915
product.categoryE:4	2,325	1,397	1,664	0,0962
product.categoryF:1	–0,144	3034,022	0,000	1,0000
product.categoryF:2	–16,019	2389,705	–0,007	0,9947
product.categoryF:3	0,286	2990,925	0,000	0,9999
product.categoryF:4	4,695	2,268	2,070	0,0384
VALUE:1	–0,096	0,128	–0,747	0,4551
VALUE:2	–0,137	0,160	–0,857	0,3916
VALUE:3	0,097	0,085	1,149	0,2506
VALUE:4	0,068	0,095	0,719	0,4723
PERC:1	0,002	0,008	0,250	0,8022
PERC:2	0,020	0,010	2,103	0,0355
PERC:3	0,014	0,007	1,871	0,0613
PERC:4	0,000	0,008	–0,002	0,9986
Sample size: n=150				
Max Log-Likelihood: –187,15; Max Log-Likelihood Null Model = –216,58				
McFadden's R^2 = 0,136; Nagerleke's R^2 = 0,344				

Source: Own elaboration.

Table 8 - Averaged Marginal effects for the five categories

Variables	**0**	**1**	**2**	**3**	**4**
Intercept	2,230	–1,096	0,574	–2,138	0,430
AreaME	0,051	–0,080	–0,067	0,131	–0,036
AreaNE	0,228	0,033	–0,039	0,062	–0,284
AreaNO	0,147	–0,108	–0,024	0,020	–0,035
Activity: on farm processing	0,138	0,135	–0,157	–0,138	0,022
Activity: primary production	0,283	0,083	–0,136	–0,198	–0,032
adhesion_PDO_PGI_other:Yes	–0,040	0,019	–0,071	–0,052	0,144
product.category: B	–2,109	1,045	–0,560	2,049	–0,426
product.category: C	–2,303	0,972	–0,451	2,194	–0,412
product.category: D	–2,058	1,016	–0,627	2,150	–0,481
product.category: E	–2,276	1,023	–0,527	2,155	–0,375
product.category: F	0,415	0,103	–1,520	0,311	0,691
VALUE	–0,001	–0,010	–0,015	0,018	0,007
PERC	–0,002	0,000	0,001	0,001	–0,001

Source: Own elaboration.

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Consumer's attitude in driving choices towards wine products derived from New Genomic Techniques (NGTs)

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Abstract

New Genomic Techniques (NGTs) present an opportunity to enhance plant resistance to parasites or diseases, reducing dependence on agrochemicals, and to extreme climatic events such as heavy rainfall or long periods of drought, thus fostering better adaptation to climate change. However, the diffusion of these techniques may encounter obstacles deriving from the reluctance of farmers, who have to sustain costs in the introduction of new technologies whose production results are still uncertain, but also the resistance of the market, given the still widespread reluctance of consumers in accepting wine products derived from the use of these technologies.
Using original survey data from 1,045 respondents, we examine Italian consumers' acceptance of and decision to buy NGT wine products. To achieve this, we developed two indicators to assess the quality of the information and the respondents' level of knowledge about NGTs, our topic of interest. These indices were incorporated into a regression model to analyse their effects on the propensity to buy NGT wine alongside the socio-economic characteristics of respondents, which were categorized through cluster analysis.
Our findings suggest a reduction in Italian consumers' distrust toward these new technologies, possibly influenced by the European institutions' proposed regulatory revision.

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Additionally, the results indicate that the quality of information plays a crucial role in the decision to purchase NGT wine. This highlights the need for higher-quality information to empower consumers, helping them reach an adequate level of knowledge that would allow them to make better-informed choices.

Introduction

Modern society is facing major challenges in food production. On the one hand, extreme climatic events and rising temperatures in some areas are making the cultivation of traditional crops more difficult. On the other hand, excessive use of pesticides and fertilisers presents serious hazards to both human health and the environment. These challenges are extremely significant in wine production, where climate change has negatively impacted grape yield and quality (Marín *et al*., 2021). Additionally, wine grapes are among the processed food samples with the highest frequency of multiple pesticide residues according to the latest report on pesticide residues in food published by the European Food Safety Authority (EFSA, 2023). Despite the increasing demand for more sustainable viticulture, individual and wine characteristics create a complex framework for decision-making. In this context, New Genomic Techniques (NGTs) present an opportunity to apply scientific progress in viticulture.

NGTs encompass a diverse group of techniques, many of which enable genome corrections without the need for DNA manipulations or altering the plant's genetic heritage in addressing wine production challenges, NGTs can enhance plant resistance to parasites or diseases, reducing dependence on agrochemicals, and extreme climatic events such as heavy rainfall or long periods of drought, thus fostering better adaptation to climate change. For these reasons, NGT products have the potential to make agri-food systems more resilient and sustainable, contributing to the innovation and sustainability objectives of the European Green Deal and Farm to Fork Strategy (European Commission, 2021).

Since 2001, the Directive 2001/18/EC has established the regulatory framework for the authorisation, supervision, and labelling of Genetically Modified Organisms (GMOs) and GM products within the European Union (EU). However, recent advancements in genome engineering have prompted a revision of the Union law. The authorisation procedures and assessment requirements for GMOs are considered disproportionate or inadequate for plants produced using these new techniques. In July 2023, the European Commission proposed a New Regulation on plants produced by certain NGTs

(COM(2023) 411 final), which was later approved by the European Parliament on 7 February 2024. The proposal suggests the exemption from regulations on GMOs of Category 1 NGT plants, defined as plants that contain genetic material from the same plant, while transgenic plants will remain subject to the GMO legislation as it stands today.

Beyond regulatory challenges, public perception is a key factor for the commercialisation of food products derived from NGTs. Reluctance toward GM products has historically shaped public opinion and has significantly hindered their development and commercialization (McFadden, 2016; Voigt & Münichsdorfer, 2019). Especially in Europe, where consumers show a clear preference for organic products – widely perceived as more 'natural' – GM products tend to be approached with greater caution (Wolf *et al.*, 2012). Scholars are actively working to understand the factors influencing consumers' food choices, including perceptions and consumption patterns (Strobbe S. *et al.*, 2023; Romeo Lironcurti S. *et al.*, 2024; Kim, J. and Fang, S. 2020). The existing literature shows how consumers remain sceptical and reluctant when making food choices, leaving uncertainties about how these choices are made and what they consider to be healthy food (Funk and Kennedy, 2016).

Particular attention should be directed to the trade-off between objective and subjective knowledge, that is, between what consumers believe they know and what they do know. The literature has also addressed the impact of this imbalance on consumer attitudes, particularly in evaluating the risks and benefits associated with genetic modification (Hwang & Nam, 2021). Consumers, despite having limited objective knowledge, may believe they know enough, and conversely, even with a high level of objective knowledge, they may perceive their subjective knowledge as low. Measuring these two types of knowledge separately can clarify which one has a more significant influence on consumer choices, providing insights for effectively communicating the benefits associated with them, thereby promoting the potential for a future market for these products (Lusk *et al.*, 2018).

The role of information in consumers' acceptance of GM foods is still a topic of debate in the literature. Some scholars strongly argue that promoting the benefits of GM foods for environmental sustainability and food safety may increase acceptance (Beghin & Gustafson, 2021; Lusk *et al.*, 2004; Wunderlich, 2019), while others believe that the role of information is not as significant (Wuepper *et al.*, 2018). Anyway, the flow of information from various sources is crucial to building consumer knowledge. Scholars have observed that the primary sources of GMO knowledge for consumers are Internet sources (77,3%), which are often used as the main method of communication to transfer information (Wunderlich & Gatto, 2015; Demaria *et al.*, 2024; Romeo Lironcurti *et al.*, 2024). Hence, it is crucial to

consider the flow of information and the sources from which it originates in order to understand the quality of the information users receive and, consequently, their actual level of knowledge on the topic. Consumer attitudes are influenced by the source of innovation, with lower confidence when it originates from private companies (Lemarie, Marette, 2022; Lusk *et al*., 2018). Acceptance tends to be higher when consumers are fully informed about the NGT innovation process, which supports the potential for NGT food market growth.

The economic analysis of the propensity to buy NGT-derived products relies on experimental surveys, as these products are not yet available on the market and aligns with previous studies on consumer behaviour towards GMO-derived foods.

This research contributes to the limited body of literature on consumer behaviour regarding NGT wine products, which has primarily focused on fungus-resistant grapes (Borello *et al*., 2021; Vecchio *et al*., 2022; Pretorius and HØJ, 2008), offering insights into how consumer knowledge and information can shape the acceptance of new agricultural technologies. Understanding these factors is crucial for promoting the market for NGT-based wines and aligning consumer attitudes with the potential benefits of these innovations. To add some evidence to the empirical literature, our study is focused on the following two research questions:

RQ1: *What is the role of information in building consumers' opinion on NGTs and how this influences their decision to buy NGT wine products?*

RQ2: *Measure the difference between respondents' subjective and objective knowledge on NGTs and investigate whether and how it drives consumer's choices.*

Our study is based on an original survey and investigates how the knowledge and perceptions of Italian consumers regarding NGTs influence their decision to purchase wine produced using these innovative methods.

Using cluster analysis, we created homogeneous groups of individuals based on their socio-economic characteristics. We also developed two indicators to assess the quality of the information and the respondents' level of knowledge regarding the topics discussed. Finally, we used the clusters and the indices in a regression model to examine their effects on the propensity to buy NGT wines.

In the following section of the article, we illustrate more in detail the methodology; in the last section we discuss the results and finally we draw our conclusions and suggest some policy recommendations.

2. Methodology and data

2.1. *Data collection*

For the analysis, we used data collected from an original survey conducted by the Appinio research agency, located in Germany, in April 2024, on a sample of 1,045 Italian consumers aged 18 and above, located in Italy. The survey was administered using computer-assisted web interviewing (CAWI) where participants were selected via simple random methodology. To ensure that the sample was representative of the Italian population in terms of gender, age, and origin – and to allow for inferences about the overall population – the collected distribution was compared with the ISTAT census data from January 2024. No significant deviations were found, confirming that the sample reflects the broader Italian population rather than a specific geographic location. Appinio's quality controls ensured a high standard of response reliability, with a margin of error of approximately 4.38% at the 95% confidence level.

2.2. *Survey design*

The survey includes 30 questions, four sections, and a segment dedicated to personal inquiries.

The first section of the survey includes ten questions on the Italian people's wine consumption habits, such as regularity of consumption, consumption places, and attributes in wine choice.

The second section evaluates participants' subjective and objective knowledge levels regarding NGTs, as well as perceptions of food and environmental safety, through a set of eight questions.

The third section explores consumers' propensity to buy (PTB) and willingness to pay for wine derived from genetic modification.

The fourth section investigates the informational tools Italian consumers rely on to build their knowledge on these topics. Finally, the survey is completed by administering personal questions about income, education, and marital status as shown in Table 1.

Table 1 - Demographic characteristics of the sample (participants N. 1,045)

		(%)
Gender	Male	(49.6)
	Female	(50.4)
Income	€0-€10,000	(15.9)
	€10,000-€20,000	(25.8)
	€20,000-€25,000	(18.9)
	€25,000-€30,000	(13.2)
	€30,000-€40,000	(14.8)
	€40,000+	(11.4)
Education	PhD in other	(3.3)
	PhD in agricultural sciences / chemistry / biology / medicine	(3.1)
	Degree in other	(28.6)
	Degree in agricultural sciences / chemistry / biology / medicine	(5.6)
	High school diploma	(49.6)
	Middle school diploma	(9.9)
Household	Married (or cohabiting) without children	(18.0)
	Married (or cohabiting) with one child	(21.5)
	Married (or cohabiting) with two or more children	(24.2)
	Single	(33.3)
	None of the above	(3.0)

Source: Own elaboration on survey data.

For the study presented in this article, we focused on specific parts of the questionnaire, particularly on questions from sections two and three. The selected questions for analysis address: (1) the PTB wine derived from NGTs; (2) the respondents' subjective and objective knowledge of NGTs; and (3) the information tools used by Italian consumers, along with the quality and frequency of their use. Additionally, we considered the main socio-demographic characteristics of the respondents. Below are the details of the questions used to construct variables for the analysis.

Table 2 - Survey questions for variable construction

PTB (Dependent variable)	**Assessment of the propensity to purchase wine derived from NGTs**
Would you buy a wine that comes from new genetic modification techniques (NGTs)?	1=Not; 2=Probably not; 3=I don't know; 4=Probably yes; 5= es
Knowledge	**Questions to evaluate the subjective and objective consumers' knowledge**
How would you assess your knowledge of new genetic modification techniques in agriculture (NGTs)?	(from 1=no knowledge to 5=excellent knowledge)
Are you familiar with or have you heard of Mutagenesis?	yes / no
Are you familiar with or have you heard of Transgenesis?	yes / no
Are you familiar with or have you heard of Cisgenesis?	yes / no
Are you familiar with or have you heard of Genome editing?	yes / no
Are you familiar with or have you heard of Crossbreeding and Selection?	yes / no
A: The new genetic modification techniques use genome editing technology	1=true; 2=false; 3=I don't know
B: The new genetic modification techniques exclusively use the genetic material of the plants themselves	1=true; 2=false; 3=I don't know
C: The new genetic modification techniques insert genes from another organism, modifying specific parts of the genes in the recipient plant	1=true ; 2=false ; 3=I don't know
D: The new genetic modification techniques involve a true genetic manipulation of the DNA	1=true; 2=false; 3=I don't know
E: The new genetic modification techniques do not use the genetic material of the plants themselves but partially insert DNA from other organisms	1=true; 2=false; 3=I don't know
F: I am not familiar with any of the mentioned techniques (not randomized)	X

Acceptance and perceived benefit	**Questions to assess the acceptability of the risks associated with these technologies**
In your opinion, are food products derived from NGTs safe for consumption?	1=Not; 2=Probably not; 3=I don't know; 4=Probably yes; 5=Yes
In your opinion, NGTs are safe for the environment?	1=Not; 2=Probably not; 3=I don't know; 4=Probably yes; 5=Yes
Do you believe that products derived from NGTs can have better nutritional values compared to conventional products?	1=Not; 2=Probably not; 3=I don't know; 4=Probably yes; 5=Yes
Information tools	**Questions to assess the acceptability of the risks associated with these technologies**
Have you heard about NGTs through 'scientific journals'?	yes / no
Have you heard about NGTs through 'podcast'?	yes / no
Have you heard about NGTs through 'newspapers/magazines'?	yes / no
Have you heard about NGTs through 'tv/radio'?	yes / no
Have you heard about NGTs through 'internet/social media'?	yes / no
Have you heard about NGTs through 'Friends and acquaintances'?	yes / no
None, I have never heard of it (not randomized)	X
Other information tools	**Open-ended response**
How often have you heard about NGTs in 'scientific journals'?	1=Once or more a week; 2=Once or more a month; 3=Once or more every 3 months; 4=Once or more every 6 months; 5=Less frequently
How often have you heard about NGTs on 'podcast''?	1=Once or more a week; 2=Once or more a month; 3=Once or more every 3 months; 4=Once or more every 6 months; 5=Less frequently
How often have you heard about NGTs in 'newspapers/magazines'?	1=Once or more a week; 2=Once or more a month; 3=Once or more every 3 months; 4=Once or more every 6 months; 5=Less frequently

How often have you heard about NGTs on 'tv/radio'?	1=Once or more a week; 2=Once or more a month; 3=Once or more every 3 months; 4=Once or more every 6 months; 5=Less frequently
How often have you heard about NGTs on the internet/social media?	1=Once or more a week; 2=Once or more a month; 3=Once or more every 3 months; 4=Once or more every 6 months; 5=Less frequently
How often have you heard about NGTs from friends and acquaintances?	1=Once or more a week; 2=Once or more a month; 3=Once or more every 3 months; 4=Once or more every 6 months; 5=Less frequently
Do you believe that information channels guide your choices correctly regarding food products derived from new genetic modification techniques (NGTs)?	1=Not; 2=Probably not; 3=I don't know; 4=Probably yes; 5= es

Source: Own elaboration on survey data.

2.3. *Methodology*

To answer the first research question, we built an index to summarize and standardize survey responses related to the quality and media used to obtain information on NGTs, including perceptions of the accuracy of the information. To achieve this, we identified the information channel with the highest quality level used by each respondent, and we then multiplied it by its maximum frequency of individual use. The quality of the information channels was assessed by assigning each tool a level of scientific information, ranging from the lowest (e.g., internet and friends) to the highest (scientific journals), as outlined in Table 3.

Table 3 - Variables for information quality index construction

Max_quality	*Quality of information channels*	Index=0 (none); index=1 (internet & friends); index=2 (Newspapers and TV; index=3 (scientific journal & podcast)
Freq_info	*Total frequency of information channels*	Index capturing the max frequency value of using information channels

Source: Own elaboration on survey data.

We then normalise it as in the following formula:

$$Info\_quality\_ratio_i = \frac{max\_quality_i * freq\_max\_quality_i}{max\ (quality * freq)} \quad (1)$$

Where $max\_quality_i$ is the highest level of quality of the information channel used by *ith* respondent; $freq\_max\_quality_i$ is the maximum frequency of the highest quality channel used by *ith* respondent in one year. The index ranges between 0 and 1, where 1 is the highest level of quality information.

Concerning the second research question, we aim to determine whether consumers accurately estimate their knowledge of NGTs or they tend to overestimate/underestimate it – that is, whether the reported level of knowledge corresponds to actual knowledge of these technologies. To do so, we compared their self-reported perceptions of their knowledge level (subjective knowledge) with their actual knowledge level on NGTs (objective knowledge). The latter is assessed through several questions regarding the main characteristics of different GM technologies. If respondents' answers about their subjective knowledge do not align with those assessing their objective knowledge, it suggests that they may either overestimate or underestimate their knowledge. Table 4 illustrates the matrix used to define the values of the index.

Table 4 - Consumer's confidence matrix

		SUBJECTIVE KNOWLEDGE		
		0 (None)	***1 (Decent)***	***2 (Excellent)***
OBJECTIVE KNOWLEDGE	***0 (None)***	***Accurate estimation***	*Overestimation*	*Overestimation*
	1 (Decent)	*Underestimation*	***Accurate estimation***	*Overestimation*
	2 (Excellent)	*Underestimation*	*Underestimation*	***Accurate estimation***

Source: Own elaboration on survey data.

To evaluate whether and to what extent these two indices help consumers to make informed choices of purchasing and can push the consumer to buy or not buy wine derived from NTG, we estimated respondents' propensity to buy NGT wine products. We codified the PTB variable in five categories.

The variable assumes value 1 if they would not buy NGTs wine products, 2 if they answered that they would probably not buy them, 3 if they are uncertain about buying NTG products or not, 4 if they would probably buy them and finally 5 if they would buy NGT wine products. This variable was used as ordinal, ranging from 1 to 5, with the values ranked in hierarchical order.

Using the PTB as the dependent variable, we regressed the two indices, which were included as explanatory variables. Additionally, we included a control variable representing homogeneous consumer groups, to account for respondents' personal characteristics. This approach allowed us to isolate the effect of these characteristics on purchasing decisions, ensuring that our estimates for the two key variables of interest – the quality of information and knowledge of technologies – remained unbiased.

More in detail, several socioeconomic variables were used to identify groups of respondents that are internally homogeneous but differ from one another based on these characteristics. This classification was achieved through a cluster analysis.

Two key considerations motivated this additional methodological step. First, it was necessary to account for interactions and correlations among the variables used in the regression, such as age, education, and income levels. Second, this approach provided additional information by identifying a summary profile of the "typical" consumer, who may have a greater or lesser propensity to purchase NGT products.

We conducted a cluster analysis using the K-median method in STATA software to identify homogeneous groups based on respondents' socio-economic profiles.

K-medians clustering in STATA is an iterative procedure that partitions the data into k groups or clusters, based on the homogeneity of individuals' characteristics. The procedure begins with k initial group centers, and observations are assigned to the group with the nearest center. The median of the observations assigned to each of the groups is calculated, and the assignment process is repeated. These steps continue until all observations remain in the same group as in the previous iteration.

Once each individual was assigned to a group, we calculated the descriptive statistics of the socioeconomic variables for each group. This allowed us to define the average profiles associated with the consumer groups.

Through this procedure, we obtained a categorical variable, where each occurrence represents a distinct 'profile' of consumers identified through the cluster analysis. As it will be shown in detail in the results section, four consumer groups with specific socioeconomic profiles were identified based on the cluster analysis applied to our data.

This categorical variable was finally included as an explanatory variable in the regression to estimate how the different socioeconomic profiles of the respondents influence their decision to buy or not to buy NGT wine products. Formally the regression equation is the follows.

$$PTB_i = \beta_{1,i} + \beta_{2,i} IQI_i + \beta_{3,i} CKI_i + \beta_{4,i} \delta_i^{profile1} + \beta_{5,i} \delta_i^{profile2} \ldots + \beta_{6,i} \delta_i^{profile\, n-1}$$

Where:

PTB_i is the ordinal variable representing the purchase choices of the *ith* consumer, which ranks in hierarchical order from "surely not purchase" to "surely purchase";

IQI_i is the level of information quality index, associated to the *ith* consumer;

CKI_i is the index of NTGs' knowledge index of the *ith* consumer;

The $\delta_i^{profile1}$ … $\delta_i^{profile1}$ are variables representing the socioeconomic profiles of consumers. These are derived from our categorical variable indicating homogeneous groups of respondents, which was recoded with N levels into N-1 indicator variables $\delta_i^{profilej}$, which gives the value 1 if observation I is in category profile j and zero otherwise.

Finally, the $\beta_{1,i} \ldots . \beta_{n,i}$ stand for the unknown model parameters that we are trying to estimate, they estimate the mean differences in Y for one unit change in the predictor X_i.

Table 5 illustrates all the variables used in the analysis.

Table 5 - Variables description

Name	Description	Values
PTB	Choice to buy NGT wine products or not	1="Not"; 2="Probably not"; 3="I don't know"; 4="Probably yes"; 5="Yes"
Info_quality_ratio	Synthetic index combining quality and frequency of information channels	Index ranging from 0 (none) to 1 (max)
Cons_confidence	Index combining consumer's objective and subjective knowledge to estimate their confidence on the subject	Index assuming value 1 (underestimation), 2 (accurate estimation), 3 (overestimation)
Age	Consumers' age	Age ranging from 18 to 65
Income	Consumers income level	1<10,000€; 2=10,000€-20,000€; 3=20,000€-25,000€; 4=25,000€-30,000€; 5=30,000€-40,000€ 6>40,000€

Name	Description	Values
Education	Educational level	1=Middle school; 2=Diploma; 3=Bachelor/Master/PhD; 4=Bachelor/Master/PhD in medicine, biology, chemistry and agrarian
Gender	Consumer's gender	Dummy variable=1 if female

Source: Own elaboration on survey data.

3. Results

In this section, we report some descriptive statistics on the variables used and the results of the regression analysis.

3.1. *Key Drivers of Consumer Purchase Behaviour*

We first focus on the PTB of NGT wine products. Even if most of the literature showed that consumers are still sceptical about genetically modified food (Wolf *et al*., 2012), based on our survey's responses, it is evident that consumers are willing to purchase wine produced from NGTs. More specifically, 59.4% of respondents answered that they would surely or probably buy it; whereas 21.2% replied that they do not know and 19.4% replied that they would not and probably not buy it.

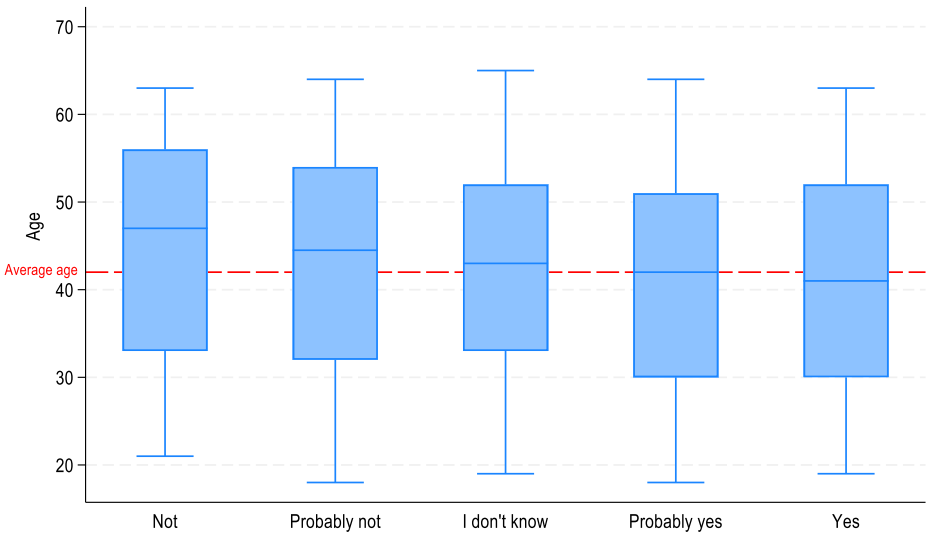
Given the role of information and knowledge in shaping consumers' acceptance of the products, we deepened the analysis of the two indices (1) and (2) to evaluate their impact on the PTB of our sample. Since almost 60% seem to be open to the idea of buying NGT wine products, we expect, on average, a high-quality level of information and accuracy of participants' knowledge on the topic.

Before analysing the role of information and of knowledge on consumer choices, we also observe the average socio-economic and personal profile of respondents to try to explain this result.

Our sample is representative of the Italian population of over 18 years old as it was collected according to the ISTAT census, as specified in the previous section, with the average age of respondents is 42 years old. As reported in Table 1, our sample is composed of 50.4% of women and earns on average between €20,000 and €25,000. Additionally, our sample has an average level of education of a high school diploma and a high percentage (more than 40%) of the sample has the highest educational level

(bachelor/master/PhD). More than 45% of the sample is married with one or more children, while 33% is single (Table 1). Figure 1, that illustrates the distribution of age of respondents grouped according to different levels of PTB, shows that the median age of purchasing groups decreases as the PTB increases indicating that young consumers seem to be more prone to purchase NGT wine products.

Figure 1 - PTB and consumer's age



Note: The box plots have a distribution range going from the lower adjacent value (5th percentile) to the upper adjacent value (95th percentile), with the box ranging from the lower hinge (25th percentile) to the upper hinge (75th percentile).
Source: Own elaboration on survey data.

Table 6 illustrates that the percentage of consumers with the highest levels of education (bachelor/master degree/PhD) increases when closer to the decision to buy NGT wine products.

When analysing consumption choices depending on the income classes, it emerges that higher income levels tend to increase the decision of consumers to buy NGT wine products, compared to lower income levels (Figure 2).

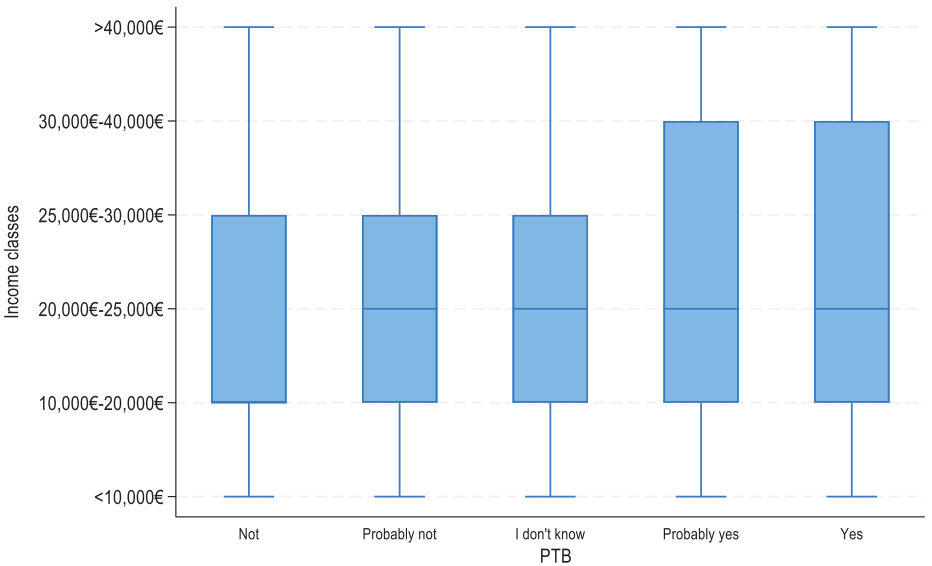
Findings suggest that higher levels of education, lower age and higher levels of income move consumers towards the decision to buy NGT wine products.

Table 6 - Consumer's educational level and PTB

Education	dip_PTB_5					
	1	2	3	4	5	Total
1	11.11	9.29	13.06	8.67	8.82	9.86
2	53.97	56.43	49.10	48.67	45.29	49.57
3	28.57	27.14	30.18	33.78	34.12	31.87
4	6.35	7.14	7.66	8.89	11.76	8.71
Total	100.00	100.00	100.00	100.00	100.00	100.00

Source: Own elaboration on survey data.

Figure 2 - PTB and consumer's income



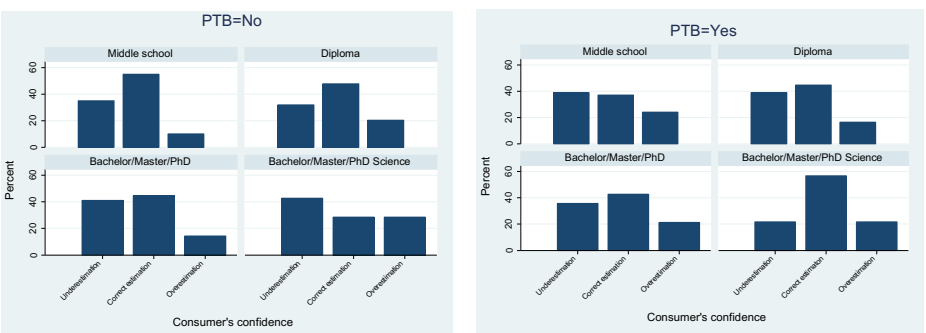
Note: The box plots have a distribution range going the lower adjacent value (5th percentile) to the upper adjacent value (95th percentile), with the box ranging from the lower hinge (25th percentile) to the upper hinge (75th percentile).
Source: Own elaboration on survey data.

Concerning consumer knowledge, the descriptive analysis reveals that many respondents claim to have a good or even excellent knowledge of genetic improvement in agriculture (respectively, 51,3% and 5% of the answers. This result is only partially consistent with Wunderlich and Gatto (2015), who highlight that consumer knowledge and awareness of

GM products are limited, with only 28.0% of Italian consumers expressing familiarity with them. However, our findings are supported by correct responses in the section where the understanding of key GM techniques was assessed (objective knowledge). In other words, we examine the discrepancy between actual knowledge and perceived knowledge, as an imbalance between the two may affect decision-making (Hwang and Nam, 2021). However, respondents claimed that traditional genetic improvement techniques were better than modern ones, such as cisgenesis, and genome editing. While only 27.1% of respondents do not know any of the proposed genetic modification techniques. A solid understanding of the subject is associated with a certain degree of positivity regarding the use and consumption of these products.

Overall, consumers tend to accurately estimate their knowledge about NGTs. However, there is an interesting difference between consumers who would buy NGT wine and those who would not. This difference is particularly noticeable among individuals with a middle school education and those with higher education in scientific fields. Our results show that for individuals with low levels of education, the decision not to purchase is not due to distorted knowledge (overestimation). Moreover, a clear bias emerges among individuals with higher levels of education, particularly in scientific fields (Figure 3).

Figure 3 - Consumer's confidence, PTB and educational levels

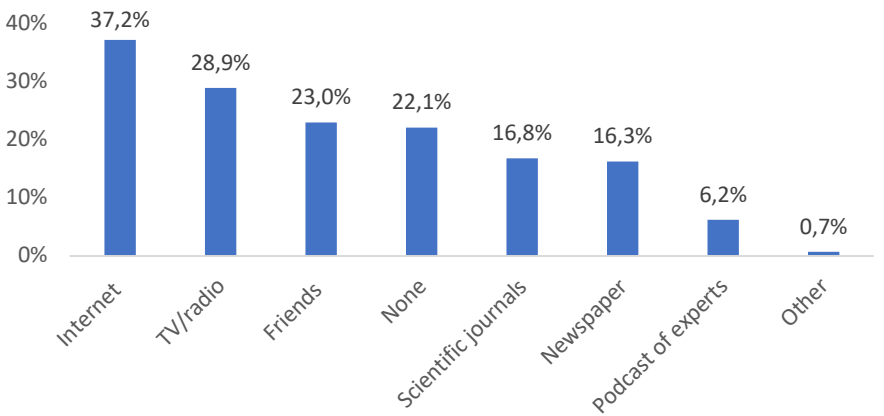


Note: In this graph "PTB = No" aggregates consumers that replied that they would "Not" and "Probably not" buy NGT wine products, and "PTB = Yes" aggregates consumers that replied "Yes" and "Probably yes" to the same question.
Source: Own elaboration on survey data.

Regarding information sources, Figure 4 shows the channels that Italian consumers most commonly use to learn about NGTs. What emerges from the descriptive results is that more than 20% of respondents stated that

does not have any knowledge on the topic. In addition, findings show that a more accurate information is underutilized: 16.8% of respondents answered that they use scientific journals to get information on the topic, while the information retrieved from the internet and social media channels consistently yield the highest results (37.2%). This last result is in line with Sendhil *et al.* (2022) that identifies the Internet as the main information source used by consumers. Other channels used for sharing information are forums and podcasts of experts, that are used by 6.2% of respondents. Finally, television and radio also remain popular choices, with 28.9% of respondents mentioning them.

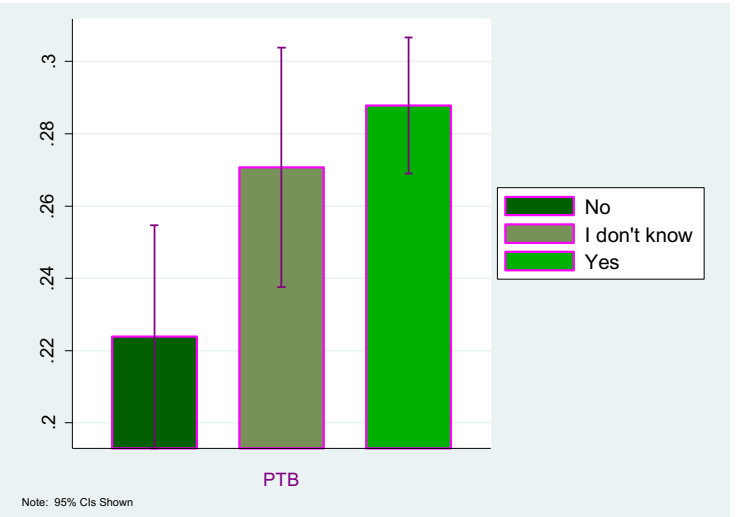
Figure 4 - Information tools



Note: Respondents were able to select multiple tools.
Source: Own elaboration on survey data.

As explained in the methodology section, we built a synthetic index that considers both the quality and frequency of the channels used by Italian consumers. Hence, we tested the relation between this index and the PTB, finding that the two variables are directly proportional (Figure 5). This indicates that the more accurate the information, the more likely consumers are to purchase NGT wine.

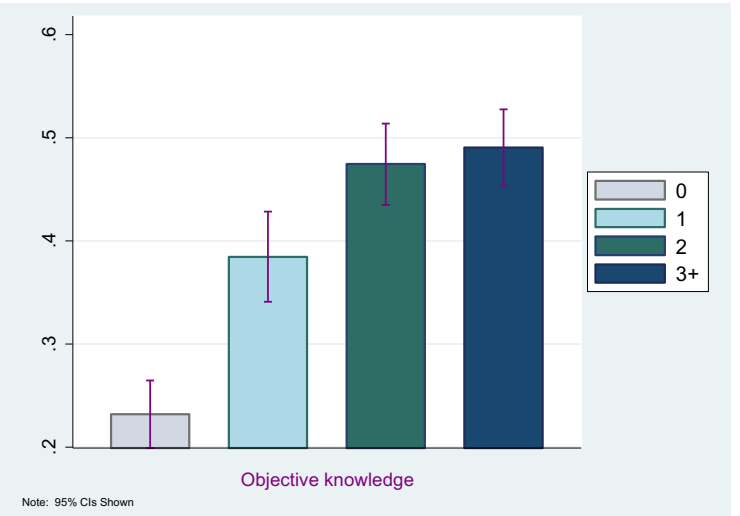
Figure 5 - Information Quality Ratio and PTB



Source: Own elaboration on survey data.

Figure 6 shows that our synthetic information quality index is positively correlated with consumers' objective knowledge on the topic, aligning with our expectations.

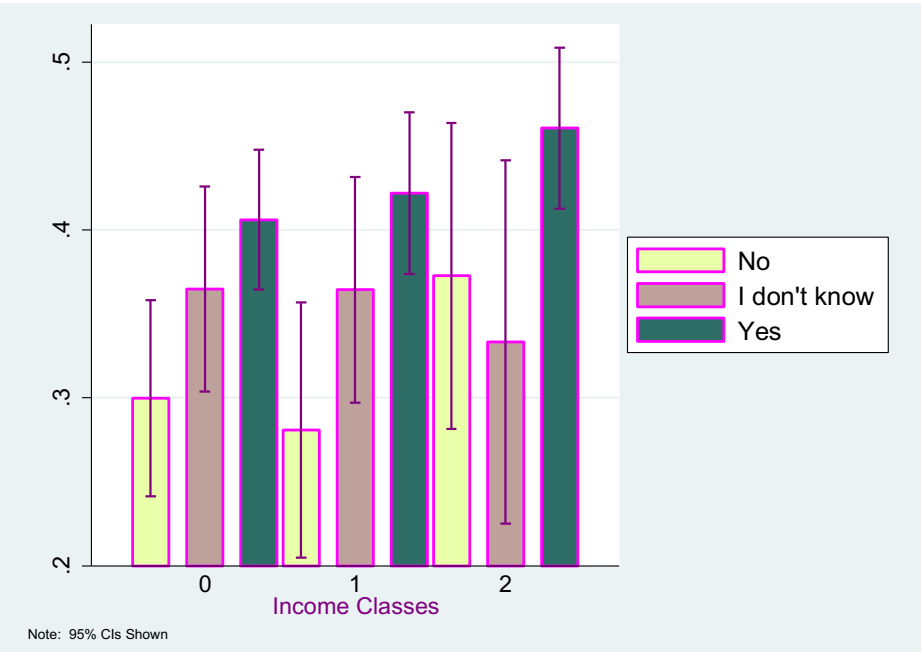
Figure 6 - Information Quality Ratio and consumer's objective knowledge on NGTs



Source: Own elaboration on survey data.

As predicted, Figure 7 shows a positive relation between the quality of information and consumers' personal income. Additionally, we find that as personal income increases, the percentage of undecided consumers decreases, with more consumers placing themselves in either the "Yes" or "Not" group.

Figure 7 - Income classes, Information Quality Ratio and PTB



Note: We aggregated income classes in the following classes: 0 = <€20,000; 1 = €20,000-€30,000 and 2 = >€30,000. In this graph "PTB = No" aggregates consumers who replied that they would "Not" and "Probably not" buy NGT wine products, and "PTB = Yes" aggregates consumers who replied "Yes" and "Probably yes" to the same question.
Source: Own elaboration on survey data.

3.2. *Regression results*

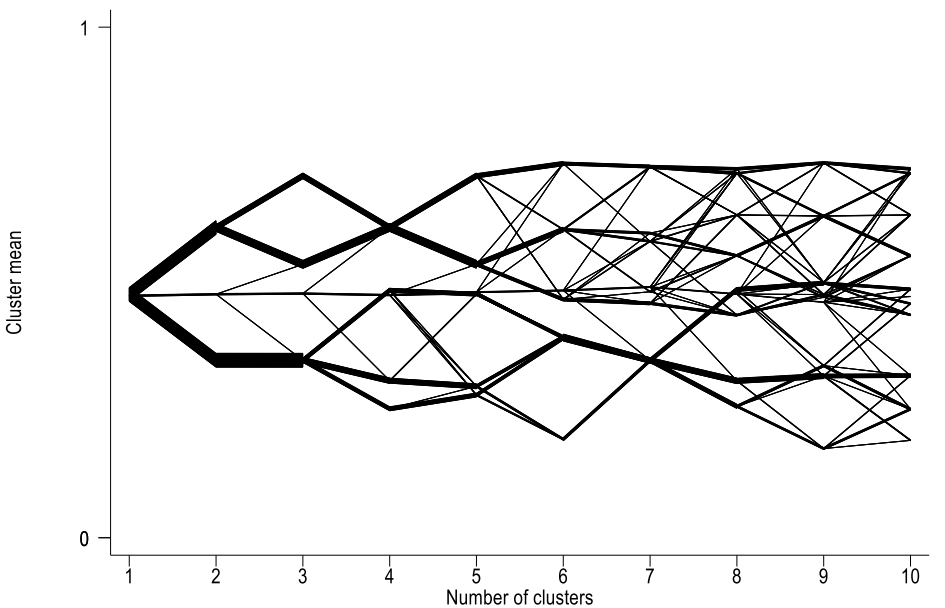
As mentioned in the methodology, the study aims to analyse the role of information acquired and consumers' knowledge in shaping their propensity to purchase NGT products. To achieve this, we use a regression model, where PTB is the dependent variable, while the two indexes, representing the quality of information and the accuracy of consumers' knowledge of each individual, are included as independent variables. By examining the coefficients of these

variables, we tried to estimate the magnitude of the effects of such measures on the choice to purchase NTG products. Additionally, to account for the effects of personnel characteristics of respondents, we included, among the independents, a categorical variable, representing different socio-economic profiles of our sample. To identify homogeneous respondent groups (clusters) from a socio-economic perspective, we apply cluster analysis using the K-medians estimation method.

The K-means (or median) is an effective non-hierarchical clustering method, where partitions are created in such a way that non-overlapping groups have no hierarchical relationships with each other. This technique is relatively stable, offering greater reliability and speed compared to hierarchical clustering. Furthermore, it tends to perform better than hierarchical clustering in the presence of errors. However, unlike hierarchical methods, the resulting clusters can be more difficult to interpret and analyse.

The procedure requires the indication of the groups to be formed. After conducting several clustering trials, a Cluster-gram graph was drawn to examine how members are assigned to clusters as the number of clusters increases. This graph is particularly useful in exploratory analysis for non-hierarchical clustering algorithms, helping to determine the optimal number of clusters to form (Fig. 8).

Figure 8 - Cluster-gram



Source: Own elaboration on survey data.

We decided to cluster our respondents into six groups, ensuring homogeneity of groups based on the following variables: age, gender, income class and educational level. It is also important to note that for this clustering method to be applied correctly, all variables must have the same scale to prevent any single variable from exerting disproportionate influence. When features are at different scales, some algorithms may be biased towards features with wider ranges, potentially leading to suboptimal model performance.

To address this, we normalized the data to ensure that all variables were on the same scale, allowing all features to be treated equally and improving the model's ability to learn from data. We then applied the Min-Max normalization of our starting variables.

Table 7 shows key statistics for the variables used in clustering, allowing us to describe the median profile of each of the six identified groups.

Table 7 - Statistics of socioeconomic characteristics of consumers groups

Cluster-ID	**N**	**Median**	**Min**	**Max**	**SD**
1					
Educational level	141	2	1	4	.7
Income classes	141	2	1	4	.8
Age (years)	141	28	18	44	6.6
Female (dummy)	141	2	2	2	0
2					
Educational level	210	3	2	4	.6
Income classes	210	3	1	6	1.5
Age (years)	210	32	18	58	9.6
Female (dummy)	210	1	1	1	0
3					
Educational level	120	2	1	3	.5
Income classes	120	1	1	3	.5
Age (years)	120	37	18	55	10.6
Female (dummy)	120	1	1	1	0
4					
Educational level	164	3	2	4	.6
Income classes	164	5	2	6	.9
Age (years)	164	40	21	64	10
Female (dummy)	164	2	2	2	0

Cluster-ID	N	Median	Min	Max	SD
5					
Educational level	213	2	1	4	.6
Income classes	213	3	1	6	1.3
Age (years)	213	51	30	64	6.8
Female (dummy)	213	2	2	2	0
6					
Educational level	197	2	1	4	.5
Income classes	197	3	1	6	1.5
Age (years)	197	55	38	65	5.9
Female (dummy)	197	1	1	1	0

Source: Own elaboration on survey data.

Based on Table 7 we can describe the main characteristics of each consumer group as follows:

1. **Group 1** (141 respondents) consists primarily of male respondents, around 28 years old, with a high school education and an annual income between 10,000 and 20,000 euros.
2. **Group 2** (210 respondents) is mainly characterized by the presence of 32-year-old women, holding a bachelor's degree or higher, with a yearly income of 20,000-25,000 euros.
3. **Group 3** (120 respondents) is mainly composed of females, approximately 37 years old, with a high school education and an income of less than 10,000 euros.
4. **Group 4** (164 respondents) differs significantly from the previous group, consisting primarily of men in their forties who are university graduates and with an annual income ranging between 30,000 and 40,000 euros.
5. **Group 5** (213 respondents) is mainly composed of men, with an average age of 51 and a high school education, and an income between 20,000 and 25,000 euros.
6. **Group 6** (197 respondents) consists mainly of women, who are on average 55 years old, with high school education and an annual income of approximately 20,000-25,000 euros.

Using PTB as a dependent variable, we performed a linear regression model, in which the two indices – representing the quality of information and consumer knowledge – as well as their socioeconomic profiles, were included as independent variables.

Table 8 shows the regression model results, while Figure 9 depicts the estimated margins for socioeconomic profile groups.

Table 8 - Regression Results (Y = Propensity to buy)

Variables	**Coefficients**
Info Quality Ratio	0.56***
Cons_confidence 1	–0.15*
Cons_confidence 2	baseline
Cons_confidence 3	–0.20**
Cluster 1	baseline
Cluster 2	0.28**
Cluster 3	0.08
Cluster 4	0.36***
Cluster 5	0.01
Cluster 6	–0.04
Constant	3.56***
Observations	1,045

Significant levels: *** p<0.01; ** p<0.05; * p<0.1.
Notes: Regression is clustered to estimate robust standard errors.

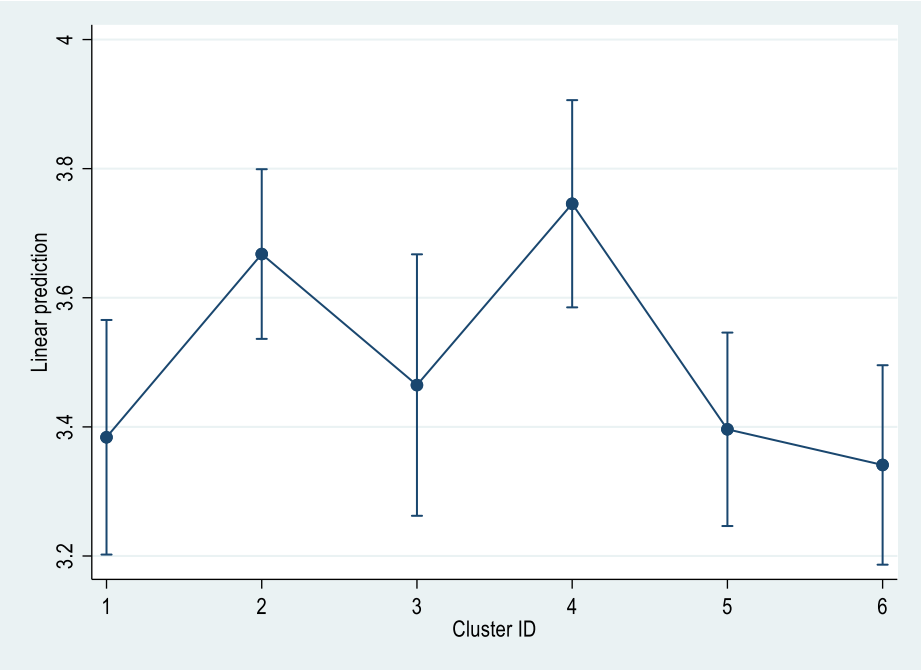
The regression results show that the information quality index positively affects consumers' PTB NGT wine. Specifically, for each additional point of the information quality index, the propensity to purchase increases by 0.56 on average, assuming all other variables remain constant. This finding suggests that a more accurate information may encourage Italian consumers to purchase of NGT wine, reinforcing the importance of information in the decision to purchase this type of food products.

Regarding consumer knowledge, proxied by an index with values of 1 (underestimates knowledge), 2 (correct estimate), and 3 (overestimates knowledge), the results show that both underestimation and overestimation reduce the propensity to purchase NGT wine. As for the socioeconomic profiles of the respondents, the results reveal positive and significant coefficients only for Cluster 2 and Cluster 4, with Cluster 1 serving as the baseline (that is keeping the intercept equal to 3.53). As previously mentioned, Cluster 1 (the baseline) primarily consists of male respondents, around 28 years old, with high school education, and an average yearly

income between 10,000 and 20,000 euros. The second profile (Cluster 2) represents a group of respondents that are on average 32-years-old women, graduates, with an average annual income of 20-25,000 euros. This group's PTB increases on average by 0.28 points compared to the baseline profile, assuming that the quality of information and the accuracy of consumer knowledge remain constant. Similarly, Cluster 4 also increases the PTB, shifting the intercept by 0.36 with respect to the baseline. This group is averagely composed of men in their forties, graduates, with an annual income ranging between 30,000 and 40,000 euros.

In summary, all else being equal, higher income and education significantly shift consumer preferences towards purchasing NGT wine. Figure 9, which depicts the marginal effects of clusters, provides a clearer view of how socioeconomic profiles impact consumers' PTB.

Figure 9 - Predictive margins of Clusters with 95% Cis



Source: Own elaboration on survey data.

Conclusions

Our findings indicate that information plays a central role in consumer purchase decisions. More specifically, the quality of information, defined as the quality of the information channel and its frequency of use, significantly increases the likelihood of purchasing NGT wine. This aligns with Wunderlich (2019), who suggests that high-quality information enables consumers to make more informed decisions that align with their beliefs.

Additionally, we observed that access to adequate information allows individuals to gain a deeper understanding of complex topics like NGTs. This is crucial because our study highlights that a multifaceted narrative about NGTs tends to confuse consumers, leading them to either underestimate or overestimate their actual knowledge. This misperception creates further barriers to purchasing decisions.

Our conclusions are also in line with the study by Hwang and Nam (2021), which emphasises how an imbalance between subjective and objective knowledge can lead to poor decision-making. Moreover, we found that trust in information sources positively influences consumers, encouraging a greater propensity to buy NGT products. One of the main limitations of this analysis is that it focuses only on certain socio-economic characteristics, which we selected based on our assessment of their relevance to the propensity to purchase NGT wine. While the results are robust, this choice may have excluded other influential factors. Further analyses will follow this initial study to explore these relationships in greater depth.

In conclusion, the dissemination of transparent and accurate information is key to promoting consumer understanding of NGTs. As our study shows, consumer attitudes and purchase intentions are shaped by the level of their knowledge, and any biases or misunderstandings can hinder the development of a market for these products. Therefore, it will be essential to promote communication from authoritative sources and ensure its widespread distribution. To support this, policymakers should consider implementing frameworks that facilitate access to accurate information, encourage reliable sources, and ensure that communication strategies are clear and accessible to all consumers. This could include developing educational programs, regulatory guidelines for information accuracy, and creating platforms that ensure transparency.

While this study provides valuable insights into the barriers to the adoption of NGTs in agriculture, it is important to note that the focus on the consumer side represents a limitation. Market resistance, driven by consumer reluctance to accept wine products, is a significant challenge. However, the willingness of farmers to invest in these new techniques is also a crucial factor that warrants further exploration. Barriers may stem from farmers' reluctance

to adopt technologies, as they would have to bear the costs of introducing new technologies whose productive results are still uncertain today. Future research that includes both consumer and producer perspectives could provide a more comprehensive understanding of the factors influencing the adoption of NGTs and offer valuable contributions to the sector.

Despite its limitations, this study serves as a preliminary effort to assess whether Italian consumers would be inclined to purchase these products. A future analysis could explore how much they would be willing to pay for NGT wine, considering the importance they place on factors such as environmental sustainability and food safety.

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Reconsidering EU Pesticide Policy to Address Sustainability

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Abstract

In January 2024, widespread farmer protests across Europe exposed growing tensions between the socioeconomic realities of agricultural production and environmental policy ambitions. Among the most contested issues, pesticide use emerged as a critical friction point, symbolizing broader dilemmas at the intersection of environmental sustainability, food security, and farmers' livelihoods. In response, the European Commission launched the Strategic Dialogue on the Future of EU Agriculture, a participatory platform aimed at fostering consensus among diverse stakeholders and redefining the direction of EU agricultural policy. This paper explores the Strategic Dialogue's contribution to shaping EU pesticide policy through a qualitative content analysis of its final report, triangulated with official stakeholder statements and EU policy documents. Focusing on the discourse on pesticide reliance reduction, sustainability trade-offs, and policy implementation challenges, the analysis applies a deductive-inductive coding framework to investigate the Dialogue's effectiveness in promoting deliberative governance and how the competing priorities were negotiated within the participatory process. The findings indicate broad stakeholder support for synthetic pesticide use reduction and restoring ecological balance, alongside recognition of the knowledge-based, structural, and economic barriers that hinder the transition. The report advocates a phased reduction strategy,

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supported by targeted financial support for small-scale farms and an increased investment in sustainable alternatives such as biocontrol and Integrated Pest Management. Furthermore, the analysis underscores the importance of ensuring balanced stakeholder representation and addressing power asymmetries in participatory policymaking. The paper contributes to understanding the potential of the Strategic Dialogue's initiative to generate cooperative responses to complex agri-environmental challenges by situating pesticide policy within the wider framework of deliberative sustainability governance.

Introduction

Sustainable food production has become one of the most pressing challenges of the 21st century. Driven by global population growth and increasing per capita consumption (Bahar *et al*., 2020), the growing demand for food is putting massive anthropogenic pressure on the environment, pushing the planet's capacity to produce enough food to its limits (Bevivino *et al*., 2020).

Addressing these challenges is key to achieving the United Nations (UN) Sustainable Development Goals (SDGs), particularly SDG2 – Zero Hunger, SDG12 – Responsible Consumption and Production, SDG13 – Climate Action, and SDG15 – Life on Land (UN, 2015).

In 2019, the European Commission (EC) adopted the European Green Deal (EGD) as an ambitious roadmap to transform Europe into the first climate-neutral continent and drive the European Union (EU) toward a resource-efficient economy (EC, 2019). The EGD includes two interrelated strategies – the Farm to Fork (F2F) Strategy (EC, 2020a) and the Biodiversity Strategy for 2030 (EC, 2020b) – aiming at reducing chemical pesticides' overall use and risk by 50 percent by 2030. Pesticide use reduction is

also part of the global policy agenda. As part of the Kunming-Montreal Global Biodiversity Framework, the UN Convention on Biological Diversity (2022) commits to cutting the overall use and risk of the most hazardous chemicals by at least 50 percent (Schneider *et al*., 2023). These initiatives prompted the revision of the EU pesticide policy to align it with the new, stringent ecological targets.

Nevertheless, the ambitious environmental requirements of the Common Agricultural Policy (CAP) 2023-2027 (EC, 2023) and the F2F strategy (EC, 2020a) have sparked significant tensions. In January 2024, longstanding discontent within the agri-food sector culminated in widespread protests across EU Member States (Finger *et al*., 2024). Whilst specific grievances

reflected the nuances of national agri-food systems, independent farmer associations expressed worries on several common matters. Indeed, they voiced shared concerns about the rapid implementation of environmental regulations, which they perceived as undermining agricultural productivity (Matthews, 2024); they pointed to climate-related risks, fluctuating and unfair incomes, rising input costs, and uncertainty created by trade agreements (Matthews, 2024) as challenges inadequately addressed by the EU's sustainability agenda, which is now perceived as overly environmentalist, at the expense of European farmers' livelihoods.

These events catalyzed swift political engagement and reconsideration of the scale and speed of the pesticide reduction targets. On 25 January 2024, recognising the need for a different approach at a time of polarization around the public debate on agricultural issues, the EC President launched the Strategic Dialogue on the Future of EU Agriculture (EC, 2024a). The initiative was designed and conceived as a forum to bring together major stakeholders from the EU agri-food sectors to reach a shared vision and foster innovative solutions. This shift in approach aimed to strike a balance between the environmental dimension of sustainability and the socioeconomic realities of EU farmers (EC, 2024a).

This paper provides a novel contribution by investigating how deliberative governance mechanisms, such as the Strategic Dialogue (SD), shape policy discourse and stakeholder alignment. The focus on pesticide reduction is particularly relevant, as it represents one of the most contentious sustainability challenges within the EU Green Deal environmental agenda, where cutting the reliance on chemical inputs has become an urgent priority. The work primarily analyses the SD's final output, a report issued on September 4th (EC, 2024b), to evaluate its effectiveness as a participatory process in consensus-building. By doing so, it contributes to emerging literature on participatory policymaking as a tool for navigating contested sustainability transitions (Newig *et al*., 2023; Frelih-Larsen *et al*., 2023; Pickering *et al*., 2022). The analysis presented here potentially anticipates and lays the groundwork for a follow-up study applying critical discourse analysis (CDA).

1. Background

Use of pesticides in agriculture

Classified as Plant Protection Products (PPPs), chemically synthesized pesticides play a pivotal role in modern agriculture by preventing, controlling, and eradicating pests, diseases, and weeds (Kim *et al*., 2017), contributing to increased crop yields and enhanced food quality (Tudi *et al*., 2021).

Pesticides encompass a broad spectrum of chemical substances and are generally classified according to their chemical structure and target organisms, i.e., herbicides, insecticides, fungicides, rodenticides, and plant growth regulators (Franco Bernardes *et al.*, 2015).

Their use in the EU remains substantial, with approximately 322,000 tons of active substances sold in 2022 (Eurostat, 2024a), even though this marks the lowest level since 2011. Pesticides are commonly applied to high-value crops such as cereals, vegetables, and fruits, which are particularly vulnerable to infestations (Lamichhane, 2017). Their application has been shown to significantly increase crop yields and decrease production losses (Fenik *et al.*, 2011; Tudi *et al.*, 2021). By lowering production costs and reducing reliance on labour-intensive practices, they contribute to sustained agricultural productivity and improved farm profitability (Bakker *et al.*, 2021; Popp *et al.*, 2013).

While chemically synthesized pesticides continue to play a key role in securing yields and protecting crop quality, their recognised environmental and health impacts have prompted a strategic shift toward more environmentally friendly practices. The EU has observed a 46 percent reduction in the use and risk of chemical pesticides by 2022, compared to the baseline average for 2015 to 2017 (EEA, 2024).

This decline is attributed to regulatory measures and increased adoption of sustainable agricultural practices. Indeed, the EU is witnessing a steady transition to organic agriculture, with organically farmed land share increasing from 5.9 percent of the EU's total utilized agricultural area (UAA) in 2012 to 10.5 percent in 2022 (Eurostat, 2024b). Under the F2F Strategy, the EU has set an ambitious target to expand this share to 25 percent by 2030 (EC, 2020a), signaling a systemic move away from chemical inputs towards more ecologically sound farming models.

Hazards of pesticide toxicity in agriculture

Despite their benefits, PPPs' improper and excessive use can pose significant risks to human health and the environment. Chemicals' inherent toxicity and relocation to non-target environmental matrices through transfer processes such as adsorption, leaching, volatilization, spray drift, and run-off (Liu *et al.*, 2015) exacerbate these risks. Only a small proportion of the applied amount is directly consumed or contacts the targeted pests (Franco Bernardes *et al.*, 2015), leaving non-target organisms vulnerable to exposure (Elgueta *et al.*, 2017), and leading to negative effects on soil and water (Fang *et al.*, 2017; Kim *et al.*, 2017), and air quality (Tuncel *et al.*, 2008). This contamination can persist due to the resistance of pesticides to degradation

(Bilal *et al*., 2019; Mitra *et al*., 2024). Moreover, pesticide residues in food represent a direct and serious threat to human health (Kim *et al*., 2017).

EU strategies for sustainable pesticide use: the role of the SUR

In recent years, the EU has intensified efforts to promote the sustainable use of pesticides, focusing on the reduction of risks associated with PPPs, particularly through the CAP 2023-2027 (EC, 2023) and the EGD (EC, 2019), both of which promote strict environmental goals. In 2020, the Commission adopted two mutually supportive strategies, namely the F2F Strategy (EC, 2020a) and the Biodiversity Strategy (EC, 2020b), setting targets to reduce the use and the risks associated with chemical pesticides and to phase out the most hazardous ones by 50 percent by 2030. To ensure the legal enforceability of these targets, the EC adopted a proposal for the Sustainable Use of Plant Protection Products Regulation (SUR) (EC, 2022a) by replacing the earlier Directive 2009/128/EC (2009). The proposal sought to address the shortcomings of the latter, which had limited success due to its non-binding targets and inconsistent implementation across Member States (EC, 2022b). Its provisions would introduce binding legislation for reduction targets (Art. 5), enhance the measurement of pesticide use (Arts. 14-16), and standardize the approaches to Integrated Pest Management (IPM) systems (Arts. 12-13). However, while intended to support sustainable agricultural practices, the SUR has sparked significant controversy (Candel *et al*., 2023), with farmers stating concerns about the economic impact of rapid pesticide use reduction. This has led to a review of the SUR targets and the broader EU approach to sustainable agriculture.

2023-2024 protests and the withdrawal of the SUR

The 2023-2024 protests spread widely throughout Europe, suggesting a "contagion effect" (Finger *et al*., 2024). After weeks of intense demonstrations, in February 2024, EC President Ursula von der Leyen announced the withdrawal of the SUR, considering it a symbol of polarization (EC, 2024c). The decision was driven by the protests and the related political pressures, exacerbated by the European Parliament's rejection of the proposal and the Council's failure to reach an agreement on alternatives (European Parliament, 2024). In the same speech, the EC President highlighted the crucial role of the SD in tackling the multifaceted challenges confronting sustainable agri-food systems (EC, 2024c).

Growing concerns about global food shortages and heightened geopolitical tensions intensified debates around pesticide-free production systems, especially when the implications for national food self-sufficiency are considered (Mack *et al*., 2023). To navigate these concerns, EU policy should align agri-food systems with planetary boundaries while ensuring equitable cost distribution. The balance between agricultural viability and environmental protection is often framed as a lose-lose situation where the gains to improve one come at the expense of the other (EEA, 2023). A major challenge will be avoiding a zero-sum approach and developing integrated solutions.

Economic implications of pesticide reduction targets

Recent ex-ante modelling exercises offer a convergent – though not identical – picture showing that a rapid 50 percent cut in chemical-pesticide use and a short-term transition to lower-risk practices are likely to impose measurable, but highly heterogeneous, macroeconomic shocks across the EU.

Barreiro-Hurle *et al*. (2021) project an average 10 percent reduction in crop yields if the EU's 2030 pesticide reduction targets were applied instantaneously without suitable effective alternatives. However, yield effects are remarkably crop- and region-specific. Bremmer *et al*. (2021) report granular EU-27 simulations with no discernible losses for several arable crops in northern Member States, yet contractions of up to 30 percent for high-value perennial crops – e.g., grapes and olives – in southern France and Italy. Rapid shifts in land use, yield levels, and yield variability could erode EU self-sufficiency in sensitive supply chains, a point repeatedly raised in Council and European Parliament negotiations (Schneider *et al*., 2023).

Bremmer *et al*. (2021) also report marginal changes in cereal prices, whereas wine- and olive-oil prices increase appreciably. Ex-ante estimates indicate a decline in EU farm income of 15-17 percent, with an uneven burden on specialized perennial systems (Barreiro-Hurle *et al*., 2021).

These projected yield and income effects explain why many stakeholders advocate a phased or hazard-based approach to pesticide use reduction.

The Strategic Dialogue: collaborative solutions for sustainable pesticide policy

The Strategic Dialogue on the Future of EU Agriculture was conceived as a collaborative forum to facilitate structured debate and to foster collaboration across a diverse spectrum of stakeholders. Chaired by Peter Stroh Schneider, it has involved 29 stakeholders, including representatives

from environmental and other Non-Governmental Organisations (NGOs), farmer and consumer organisations, agri-industry and business players, and research institutions. Over the seven-month-long deliberative process, plenary sessions have focused on four critical priority areas, i.e., enhancing prospects for farmers and rural communities, sustaining agriculture within planetary boundaries, advancing knowledge and technological innovation, and promoting a competitive and sustainable EU food system (EC, 2024a).

These focal points reflect a growing recognition that the shift toward sustainable agriculture requires both regulatory targets and support mechanisms for the implementation of alternative practices (Boix-Fayos & Vente, 2023), including IPM, biocontrol methods, and organic farming.

The Dialogue concluded with the publication of the final report titled "A Shared Prospect for Farming and Food in Europe", adopted by consensus among the 29 participants; this is intended to inform the EC's work on the Vision for Agriculture and Food and a new SUR proposal (EC, 2024a).

Unlike traditional public consultations, which typically gather feedback from the public or stakeholders through formal submissions, the SD fostered an interactive and iterative process, thus encouraging in-depth discussion. Often framed as a highly polarized issue, with stakeholders holding opposing views, pesticide policy appeared to benefit from this structured multi-stakeholder approach. Deliberative processes, such as the SD, allow stakeholders to explore each other's positions and work toward common ground, fostering collaborative solutions. This approach aligns with recent research on the role of participatory processes in sustainability governance and policy design (Frelih-Larsen *et al*., 2023), suggesting that diverse stakeholder engagement is the key to achieving both ecological and socioeconomic goals.

2. Materials and Methods

This study employs a qualitative methodological approach to examine how the SD frames and navigates the contested issue of pesticide policy within the broader landscape of EU agricultural sustainability. The SD was launched by the EC in early 2024 as a participatory initiative designed to foster dialogue among key actors in the EU agri-food system and to identify consensual pathways for the future of agriculture. Structured around seven plenary sessions held in Brussels between January and August 2024, the SD engaged a wide spectrum of stakeholders, including farmer associations, agricultural cooperatives, agri-food businesses, NGOs, civil society organisations, financial institutions, and academic researchers. This design aimed to ensure the integration of several, often conflicting, perspectives regarding the future

of EU agriculture. Moderators played a role in facilitating the co-construction of shared visions.

To analyse how pesticide governance was addressed within the SD deliberative process, the study applies qualitative content analysis (QCA) to the SD final output (Hsieh & Shannon, 2005; Mayring, 2014; Assarroudi *et al.*, 2018). QCA is regarded as particularly well suited to policy research in sustainability contexts, where existing theoretical insights guide inquiry while allowing room for inductively emerging categories. This methodological approach aligns with the study's theoretical grounding in deliberative sustainability governance, which examines how inclusive policy processes cope with socio-ecological trade-offs while fostering collective learning in contexts marked by uncertainty, competing values, and diverse interests (Newig *et al.*, 2023; Pickering *et al.*, 2022; Hammond, 2020). Accordingly, the analysis seeks to assess the SD's capacity to mediate tensions between environmental imperatives – i.e., pesticide use reduction – and economic and social concerns voiced by agricultural stakeholders.

The primary document analysed is the final SD report (EC, 2024b), complemented by a selection of official EU legislative texts, including the F2F (EC, 2020a) and Biodiversity Strategy (EC, 2020b), the CAP (EC, 2023) and the SUR proposal (EC, 2022a), which provide the institutional and regulatory backdrop for the Dialogue. Additional data were drawn from publicly available statements, position papers, and organisational reports from SD participants, allowing for the triangulation of discursive positions across stakeholder groups. A purposive sampling strategy was employed to select the documents based on two inclusion criteria: (i) institutional authoritativeness and (ii) relevance to the study's research questions, particularly regarding pesticide regulation, environmental sustainability, and agricultural policy trade-offs. The unit of analysis is thematic, meaning that themes, rather than words or isolated phrases, serve as the core coding units. This allows for an interpretive analysis of explicit policy content and underlying normative framings, including problem definitions and proposed solutions.

The analytical process integrated deductive and inductive coding. A preliminary coding framework was developed based on the existing literature on pesticide regulation, sustainability governance, and participatory policymaking. Categories included justification for pesticide reduction, competing policy objectives and tradeoffs, proposed alternatives, governance mechanisms, and stakeholder inclusion and influence. As analysis progressed, new sub-themes were added to capture emerging discursive patterns, including the framing of risk, the role of innovation, and the invocation of fairness and feasibility.

Stakeholder representation and power asymmetries within the deliberative process were mapped through the clustering scheme adapted from Frelih-

Larsen *et al.* (2023), as illustrated in Table I. The framework categorizes actors based on their affiliations – environmental and other NGOs, farmers and agricultural workers, research, and agri-food industry, business, and trade – and interests, enabling a more granular understanding of the relational dynamics shaping consensus and dissent in the Dialogue. Overall, the methodological approach is consistent with the study's overarching aim of exploring the extent to which deliberative processes support cooperative responses to contested sustainability issues. Although this study focuses on discursive construction and stakeholder positioning, it could lay the foundation for a follow-up analysis employing CDA to deeply interrogate power relations and exclusions within the SD's output.

3. Results

The SD report shows a long-term vision to transform EU agri-food systems by 2035-2040, emphasising the functional integration of environmental, social, economic, and institutional factors at each stage of the agri-food value chain. This approach aims to move beyond compromise-driven solutions, favoring collaborative responses that integrate ecological sustainability with economic resilience. Indeed, the report provides a set of political principles and specific concrete recommendations addressed to both the EU and the Member States levels, which align with the EGD's ambitious environmental targets.

The Dialogue's process involved 29 key stakeholders, representing a broad cross-section of vested interests, including environmental and animal NGOs, farmer and agricultural worker associations, agri-industry representatives, consumer protection groups, and academia.

Official participant organisations are clustered according to their affiliations and interests.

The SD acknowledges that transitioning to sustainable agri-food systems inevitably involves conflicting interests and complex trade-offs that can only be solved through careful balancing.

Moderators of the working groups played a critical role in fostering cohesion and facilitating the development of shared perspectives. Indeed, the structured process allowed opposing views to be aired, advancing deliberation and striving for consensus. Yet, power dynamics among stakeholders have also influenced the discussion as participants represented varying degrees of power over agricultural policy and financial resources. In other words, while the SD report seems to reflect an agreed direction, there may be imbalances in stakeholder representation, with industry and business, and NGOs wielding different types of influence compared to smaller farmer associations.

Table I - Clustering of participant organisations in the Strategic Dialogue on the future of EU agriculture

Cluster	Description	Participants
Environmental NGOs	Environmental charities focused on ecological advocacy	BirdLife Europe & Central Asia; European Environmental Bureau (EEB); Greenpeace Europe
Other NGOs	Charities focused on animals, food, and rural development	Agroecology Europe; Compassion in World Farming – Eurogroup for Animals; European LEADER Association for Rural Development (ELARD); European Food Banks Federation (FEBA); Rural Youth Europe; Slow Food
Farmers/ Agricultural Workers	Farming unions and organisations focused on agriculture	European Council of Young Farmers (CEJA); General Confederation of Agricultural Cooperatives (COGECA); Committee of Professional Agricultural Organisations (COPA); European Federation of Food, Agriculture, and Tourism Trade Unions (EFFAT); European Coordination Via Campesina (ECVC); IFOAM Organics Europe
Research	Academic researchers, and evidence-led entities	Stockholm Resilience Centre – EURAGRI; Wageningen University & Research
Agri-Industry/ Business/Trade	Industry, agrichemical business, biocontrol business, retail, consumer protection, financial services	European Consumer Organisation (BEUC); European Liaison Committee for Agricultural and Agri-Food Trade (CELCAA); European Association of Co-operative Banks (EACB); EuropaBio; EuroCommerce; European Investment Bank (EIB); European Landowners Organisation (ELO); Euroseeds; Fertilizers Europe; FoodDrinkEurope; FoodServiceEurope; Employers' Group of Professional Agricultural Organisations (GEOPA)

Source: Authors' elaboration adapted from Frelih-Larsen, Chivers, Herb, Mills, & Reed (2023).

Key recommendations focused on phased reduction in synthetic pesticide use and the promotion of unconventional pest management strategies, notably IPM and biocontrol methods. However, although promising, these alternatives

require larger adoption to achieve the EU environmental targets. Current limitations are attributed to the challenges in securing support and price premiums through labeling systems (Deguine *et al.*, 2021; Lefebvre *et al.*, 2015). Accordingly, the SD indicated establishing premium support systems through quality certifications and eco-labels to increase consumer support and market viability. These would enable sustainable products to reach wider markets, improving the visibility and economic viability of farms willing to invest in non-chemical methods. Moreover, the report suggests enhancing accountability by establishing an EU system for transparent and comparable assessments of sustainability performance and pesticide use across EU Member States. An incremental approach would provide flexibility to adapt to different national contexts.

In addition, the report advocates for increased investment in research to scale up practical and low-risk alternatives to conventional pesticides. It highlights priority areas for research, including biocontrol technologies, IPM advancements, and soil management practices that bolster ecological resilience; in this regard, it suggests that collaborative public-private investment could drive the required innovation to accelerate the sustainability transition.

Expanded adoption of IPM and biocontrol will require Member States to address the economic challenges associated with sustainability transitions. Acknowledging the difficulties faced by smaller farms, the SD outlines several actionable pathways for potential policy adjustments. Recommendations include providing financial support beyond existing CAP mechanisms to help smaller operations to reduce pesticide dependence – i.e., targeted subsidies and incentives for adopting biocontrol, IPM, and organic farming practices. This support would help to address the high upfront costs associated with shifting to more sustainable pest management methods.

The resulting recommendations reflected areas of agreement and underlying tensions. For instance, Environmental NGOs and consumer protection groups strongly advocated for stringent pesticide use reduction and enhanced sustainability measures. Conversely, agricultural and farmers' organisations raised concerns about the economic feasibility of rapid transitions, underscoring the need for financial support and phased adaptation.

Overall, the report reflects a broad consensus on reducing reliance on chemical inputs and increasing support for viable, non-toxic alternatives, thus mirroring EGD goals. However, it advocates for a more gradual and financially supported transition, which would balance the urgency to achieve ecological objectives with the economic pressures on EU farmers. Agri-food systems should be progressively transformed, enhancing pesticide use efficiency while encouraging the adoption of substitutes.

4. Policy Recommendations

The EU agri-food sector stands at the crossroads of environmental sustainability and agricultural productivity, necessitating significant innovation for non-conventional PPPs for pest and disease control (Galli *et al.*, 2024). Transitioning to sustainable agricultural practices requires investments in alternative solutions, including precision agriculture (Sishodia *et al.*, 2020), biocontrol (Hulot & Hiller, 2021), and IPM systems (Deguine *et al.*, 2021). These approaches were reaffirmed in the SD final report (EC, 2024b), advocating a systemic shift toward low-input farming models through a phased reduction in the use of synthetic chemicals coupled with targeted financial support.

Sustainable practices have proven effective in maintaining satisfactory yields while lowering reliance on chemicals (Ratto *et al.*, 2022; Pecenkaa *et al.*, 2021). Moreover, studies have shown that significantly lower pesticide inputs result in equivalent yields. Data from 946 French conventional arable holdings indicate that total pesticide use could be reduced by roughly 42 percent without any loss of either yield or gross margin in 59 percent of the farms analysed, with the largest savings potential on high-input holdings (Lechenet *et al.*, 2017). Framing outreach around such figures could help dispel the perception that lower chemical intensity necessarily entails lower profits. However, training and capacity-building programs should be prioritized to equip farmers with the skills and knowledge needed for the adoption of low pesticide-input pest management practices.

Among the alternatives discussed, the SD strongly supports biocontrol techniques, e.g., natural enemies, beneficial microorganisms, and substances of biological origin. These methods can offer targeted pest control with fewer environmental externalities. IPM also balances productivity with ecological concerns, yet its adoption remains uneven and requires enhanced institutional support and financial incentives (Deguine *et al.*, 2021). Precision agriculture tools, such as satellite-based monitoring and digital application systems, can further help to minimize the use of chemical inputs through more targeted treatment. Furthermore, although not widely adopted at scale, mechanical and physical methods, including steam or hot water weeding, have been explored as chemical-free alternatives, particularly in small-scale and organic systems (Riemens *et al.*, 2022).

The role of prevention has emerged as equally critical. Crop rotation, soil fertility management, biodiversity enhancement, and the restoration and conservation of ecological infrastructures are essential to reduce pest pressure and chemical dependency. As emphasised in the SD report (C.2.2; C.2.4), preventive approaches should be seen as critical for sustainable pest

management, aligning with agroecological principles and fostering long-term resilience (EC, 2024b).

However, despite the environmental rationale and agronomic potential of these alternatives, the risk of large production loss due to pests remains a prominent obstacle to the reduction in the use of pesticides (Chèze *et al*., 2020). Financial stability during the adaptation process is essential and must be ensured by subsidies tailored to the needs of farmers with low and insecure incomes to help them adopt riskier low-pesticide practices. Environmental and health improvements may not be sufficient motivation for some farmers to accept changes in their current practices.

In this regard, the SD recommends specific support mechanisms, including targeted payments for the adoption of IPM and biocontrol (C.1.3), as well as broader access to innovation through public-private research partnerships and advisory services (C.5.1) (EC, 2024b). Area-based payments, such as direct payments in Pillar 1 of the CAP (EC, 2023), may contribute to income stability and indirectly support pesticide reduction by alleviating economic pressures. Conversely, result-based payments could be less conducive to such reductions, as they often entail higher risk exposure and uncertainty for farmers, potentially discouraging the adoption of low-input practices.

A further enabler of the transition could be the establishment of a coherent policy framework. The SD report calls for the implementation of a benchmarking system to monitor sustainability performance at the farm level, including indicators related to pesticide use (C.1.2) (EC, 2024b). This would facilitate the comparison of practices, improve transparency, and create incentives for those adopting non-chemical approaches. Moreover, to enhance market viability, the Dialogue also recommends the development of quality certification schemes and eco-labels that reward farms that commit to reducing pesticide use while providing consumers with reliable information about environmental performance.

Reflecting policy efforts to support a phased reduction in the use of chemical pesticides, the EC's draft proposal of January 6th (EC, 2025), introduces a revised labeling" scheme for PPPs, repealing Regulation (EU) No 547/2011 (2011). The proposed framework would employ a colour-coded classification system to indicate whether a product is considered low-risk or qualifies as a "candidate for substitution". By visually differentiating products based on their hazard profile, this approach supports informed decision-making and gradual behavioral change.

Governance and policymaking must evolve to address the complexities of sustainability in the agricultural sector. A participatory governance model, such as the European Board on Agriculture and Food (EBAF) (EC, 2024d), could provide a stable platform for multi-stakeholder participation and collaboration among farmers, policymakers, and civil society. The board has

been set up for five years. However, its implementation requires the adoption of a robust framework by the EU institutions to ensure the EBAF serves as an inclusive, well-balanced, and effective advisory body to the EC (IEEP, 2024).

Conclusions

The debate surrounding pesticide reduction in EU agri-food systems highlights the intricate challenge of reconciling environmental sustainability with agricultural productivity and economic viability.

Convened to address growing tensions and discontent within the agri-food sector, the SD provided a structured platform for fostering collaboration and deliberation among diverse stakeholders from the EU agri-food sector. Its participatory approach sought to mediate polarization and produce actionable recommendations for the transition toward integrated farming systems.

Overall, the SD's outcomes emphasise the effectiveness of inclusive, multi-stakeholder engagement in formulating policy solutions that integrate both ecological goals and socioeconomic realities.

The final report advocates for a phased reduction in pesticide use, enhanced support mechanisms for small farms, and investment in research on biocontrol and IPM. By prioritizing gradual adaptation and tailored support, the SD highlights the need to alleviate the economic burden on small farmers while advancing toward the EGD's ambitious ecological targets, mirroring other studies stating the need to combine market incentives and investments in technological advancement to foster a larger adoption of sustainable agricultural practices (Mack *et al*., 2023; Deguine *et al*., 2021; Lefebvre *et al*., 2015). This approach shows that structured, participatory frameworks can yield balanced, pragmatic solutions potentially more effectively than top-down regulation or traditional public consultations alone. However, while the SD achieved consensus, not all interests may have been equally represented, pointing to areas where consultative frameworks might improve. The success of the SD indicates the value of establishing a permanent consultative body, such as the proposed EBAF, providing a more balanced representation from academic institutions, farmers, environmental and animal protection groups, and consumer advocacy. This model could help mitigate polarization and promote sustainable transitions in the EU's diverse landscape, offering a model for policy areas where conflicting interests need to be reconciled to achieve long-term sustainability.

This paper provides a timely analysis of the SD's approach and outcomes, providing insights into how collaborative policymaking can help reconcile challenging priorities. However, given the power dynamics and varying levels

of influence among stakeholders, the SD initiative raises questions about inclusivity and effectiveness.

Although this paper provides valuable insights into the SD deliberative process and its outcomes, it is not without its limitations. The study acknowledges that this is a preliminary analysis and that further research is needed. The focus on pesticide reduction may not fully capture the broader scope of the SD. Moreover, while QCA provides an in-depth view of policy discourse and decision-making, it does not address the causal effects of policy interventions. Additionally, the reliance on textual sources might imply that informal political negotiations or stakeholder influences are not reflected. Despite these limitations, the results obtained give useful indications for subsequent in-depth studies.

A follow-up study applying CDA to the Dialogue's report will enhance this preliminary assessment by investigating how discourse patterns, participant influence, power dynamics, and points of contention influenced the SD's recommendations. This could reveal whether the SD has effectively balanced the diverse stakeholder interests and competing priorities or if structural adjustments are needed for greater equity in representation. Further research could also explore strategies for mitigating power imbalances within the EBAF initiative.

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La passione per le conoscenze

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