On the blockchain adoption in fisheries and aquaculture supply chains: An empirical study on Indian stakeholders' perceptions and the US consumer preferences for blockchain-enabled shrimp supply chain

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DECLARATION OF THE ORIGINAL AUTHORSHIP

I confirm that this is my own work, and the use of all material from other sources has been properly and fully acknowledged.

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ABSTRACT

Global seafood supply chains are fragmented, complex, and non-transparent, resulting in a lack of sufficient traceability and often raising concerns about their integrity. In such diverse supply chains, several stakeholders lack an integrated view of the whole supply chain. This low transparency creates various obstacles and intricacies related to food safety, security, traceability, and verification practices. Among all kinds of seafood, shrimp is one of the most traded and consumed products. However, complex shrimp supply chains often lack traceability, and have noted frequent occurrences of contamination frauds and food safety incidents. India is one of the top shrimp producers and exporters but frequently faces food safety concerns due to banned antibiotic detection in exports. The lack of visibility in the Indian Shrimp Supply Chain (ISSC) makes it challenging to address these concerns and comply with export standards, affecting consumer trust. The existing literature shows a significant gap in exploring innovative technology in ISSC solutions to address these challenges. Therefore, this thesis investigates the adoption of Blockchain Technology (BT), which promises to offer end-to-end transparency and trust with enhanced traceability in the ISSC. Thus, this thesis aims to explore ISSC stakeholder views on BT adoption and investigate consumer preferences for BT traceable shrimps. First, we conducted qualitative in-depth interviews with ISSC stakeholders to understand their perceptions and opinions on the existing sector challenges, solutions, and benefits and costs of BT adoption in ISSC. The findings revealed that most ISSC stakeholders are enthusiastic about adopting BT, as it enhances transparency and visibility in the sector by providing immutable and real-time data availability. Additionally, stakeholders agreed to accept higher initial costs, which would eventually decrease as BT matures. Second, the US is the top shrimp market for Indian shrimps, and thus, we used discrete choice experiments to study US consumers' willingness to pay (WTP) for BT traceable shrimp. Our results indicate a high willingness of shrimp consumers to pay a premium for BT-certified shrimp. Furthermore, we observed heterogeneity among consumers, where young consumers from high-income groups with children under 18 in households showed a higher WTP for BT-certified shrimp. Communication messages with food safety benefits of BT noted the highest WTP. Lastly, consumers have shown positive acceptance of and readiness for BT.

Keywords: *Blockchain, shrimp supply chain, Indian shrimp, choice experiment, willingness-to-pay*

TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

List of abbreviations and acronyms

Agri-food supply chain (AFSC)

Akaike's information criterion (AIC)

Bayesian Information Criterion (BIC)

Best Aquaculture practice (BAP)

Blockchain technology (BT)

Cheap task (CT)

Discrete Choice Experiment (DCE)

Example (e.g.)

Fishery and aquaculture sector (FAS)

Fishery and aquaculture supply chain (FASC)

Food and Agriculture Organisation (FAO)

Food and Drugs Administration (FDA)

Hazzard Analysis Critical Control Point (HACCP)

Id is/that is (i.e.)

Illegal, Unreported and Unregulated (IUU)

Indian Shrimp Supply Chain (ISSC)

Internet of Things (IoT)

Marine Stewardship Council (MSC)

Metric tonnes (MT)

Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA)

Quick Response (code) (QR)

Radio Frequency Identification (RFID)

Technology Acceptance Model (TAM)

Technology Readiness Index (TRI)

United States (of America) (US)

Videre licet/Which is (viz.)

Willingness-to-Pay (WTP)

CHAPTER 1: Introduction

This chapter introduces the thesis topic and is divided into seven sections. The first section provides background to the current scenario of the agri-food supply chains (AFSC), including the Fisheries and Aquaculture Supply Chain (FASC), followed by a section highlighting various economics research problems in contemporary FASC, the third section discusses blockchain technology (BT) its definition, advantages and limitations, followed by a fourth section on motivations of the thesis. The fifth section portrays the aims, objectives, and research questions of the study, followed by the sixth and seventh sections on potential contributions of the thesis and outline of the thesis, respectively.

1.1 Background

The globalisation of agri-food products has made AFSC highly complex and vague, making it difficult for businesses to have a holistic view of their operations, which often raises concerns about their integrity (Esteki et al., 2019). The non-transparent state of current AFSCs affects the adequate provenance of agri-food products. In addition, with a recurring number of food safety and food fraud incidents, the five pillars of food systems, i.e. food quality, food safety, food authenticity, food defence, and food security in the current AFSCs, are at stake and questioned (Keogh et al., 2020). These incidents have a substantial economic impact on all stakeholders, mainly due to the effect on their trade in the international markets (Treiblmaier & Garaus, 2022; Xu et al., 2020). This low transparency creates problems in the supply chain, including food safety, security, traceability, and verification (Antonucci et al., 2019b).

This has led to increasing demand for greater transparency on the origin of food, cultivation methods, harvesting, production conditions, and environmental impact (Demestichas et al., 2020; Patel et al., 2022). However, the rapid growth of the global population has resulted in the rise of food demand, which causes a high chance of opportunistic and fraudulent behaviour which promotes malpractices by few stakeholders, which further reduces the reliability on existing AFSCs (Eastham et al., 2017; Behnke & Janssen, 2020; Bosona & Gebresenbet, 2013; Salah et al., 2019). These fraudulent activities cause severe food-borne illness outbreaks (Pearson et al., 2019; Pizzuti et al., 2014; Yiannas, 2018), which makes it more complex to trace the source of food contamination during food recall (Xiong et al., 2020). Thus, the complexity of these AFSCs has created the need for transparency and end-to-end traceability in the farm-to-fork supply chain operations (Madumidha et al., 2019; Pakseresht et al., 2023; Saurabh & Dey, 2020).

Additionally, consumers have become more demanding for transparency in AFSCs to support responsible consumption practices (Francisco & Swanson, 2018; Mirabelli & Solina, 2020; Wognum et al., 2011; Abeyratne & Monfared, 2016). Authentic information about food products, such as the origin, production methods, and sustainability standards, for example sustainably sourced fish helps consumers to make informed decisions on food purchase (Di Vita et al., 2022; Mccallum et al., 2022; Tran et al., 2022; Wongprawmas et al., 2022). However, this demand has resulted in various certification labels that consumers need to trust without being able to verify or understand their meaning due to a lack of a trustworthy traceability mechanism (Jacquet & Pauly, 2018; Rao et al., 2023). Therefore, it has become vital for businesses such as retailers to make sure these labels and certifications are verified correctly to address the rising consumer demand for sustainable production practices (Engbers, 2020).

Similar to agri-food products, seafood is one of the world's most traded commodities but has long and complex supply chains, with an extensive network of stakeholders from bait to retail (Manning & Soon, 2014). FASC faces several challenges, such as fraud in species substitution, mislabelling, species adulteration, and Illegal, Unreported, and Unregulated (IUU) substitution of low-quality products (Luque & Donlan, 2019; Sylvester, 2019). Such fraud occurrences have affected consumer trust and confidence (Cawthorn et al., 2018;

FAO,2017; Kamilaris et al., 2019; and Luque and Donlan, 2019). Thus, due to frequent fraudulent incidents in the news, seafood consumers are demanding more information on the origin of fish, sustainability labels, production method, and accurate time of catch, so as to make informed decisions when buying seafood (Cruz & da Cruz, 2020). Besides food fraud, in several cases, consumers are at high risk of getting exposed to health risks due to the use of banned chemicals such as antibiotics and other harmful pathogens in seafood, leading to high food quality and control concerns globally (Le et al., 2020; Hamilton et al., 2018). Thus, it has become vital to monitor the entire end-to-end FASC, from wild capture or farm production to supermarket shelves (Di Vita et al., 2022; Fox et al., 2018; He, 2010). The following section describes the various ongoing economic research problems in the FASC.

1.2 Economic research problems in the FASC

1.2.1 Food safety concerns and economic impact

Food safety issues decrease the quality of seafood products, which in turn reduces their nutritional and economic value. For instance, the identification of pathogens and antibiotics in seafood causes their rejection in significant markets such as the EU and the US (Jennings et al., 2016; Okocha et al., 2018). The use of banned chemicals, antibiotics and harmful pathogens exposes consumers to health risks, raising health and safety concerns, which affects trust in overall FASC (Gopi et al., 2019; Lawrence et al., 2022; Mai et al., 2010; Hamilton et al., 2018). In addition, food safety issues lead to food waste and discarding, which adds more economic loss to the industry (FAO, 2018; Keogh et al., 2020). Moreover, food safety occurrences can also cause the loss of market due to bans, restrictions, etc., which affects overall economic loss for the sector (Kruijssen et al., 2020). Furthermore, FASC stakeholders, such as farmers, producers, processors, and exporters, often report economic losses due to expensive recall of faulty food coupled with the compromise for brand reputation and have expressed the need for efficient solutions to tackle food safety issues (Le et al., 2020; Xiong et al., 2020).

1.2.2 Consumer demand for transparency

Consumers are demanding more transparency in FASC to support responsible consumption practices (Hang et al., 2020; Lagoudakis et al., 2020; Ringsberg, 2014; Salunke et al., 2020; Surekha et al., 2020 ; Abeyratne & Monfared, 2016). Authentic information about food products, such as the origin, production methods, and use of pesticides, enables consumers to make an informed decision to purchase seafood (Cantillo et al., 2020; Di Vita et al., 2022; Gopi et al., 2019; Love et al., 2021). However, currently, there is only a provision for some certification labels that consumers have to trust without being able to verify or understand their actual value to them (Jacquet & Pauly, 2018; Rao et al., 2023). Therefore, it has become vital for FASC stakeholders to start investing in technologies to support consumers in verifying labels and certifications to make informed choices (Engbers, 2020).

1.2.3 Stakeholder coordination and information asymmetry

The data management practices in FASC showcase a gap for information asymmetries due to the presence of middlemen and a lack of efficient data management, wherein all record their own copies of transactions (Hastig & Sodhi, 2020; Kayikci et al., 2020; Scuderi et al., 2019; Tönnissen & Teuteberg, 2020; Tsolakis et al., 2021). This is due to a lack of coordination among stakeholders where throughout the journey of seafood, the data captured by multiple stakeholders using different information management systems and software platforms develops a risk of the inaccuracy of the data leasing reduced transparency and authenticity (Ray et al., 2019; Tayal et al., 2021). Moreover, the asymmetries of information make certification and labels less credible and typically favour bigger organisations or IT systems implementers, which prevents the optimisation of supply chain efficiency (Engbers, 2020). Additionally, there is a need for technology adoption to enhance visibility and transparency and to facilitate better coordination among all stakeholders (Rogerson & Parry, 2020). Thus, overall information asymmetry leads to an advantage for middlemen to earn massive commissions due to a lack of visibility in the system (Kimani et al., 2020; Purcell et al., 2017).

1.2.4 Seafood frauds, traceability and economic impact

The seafood industry is one of the largest and oldest market sectors worldwide but it continues to face challenges such as fraud (intentional species substitution, IUU fishing, a mixture of seafood species), high incidence of foodborne illness, and fraudulent labelling are some significant concerns (Ray, 2019; Sylvester, 2019). Despite being one of the largest sectors, it is often unregulated and unreported, where 89% of global fish stocks are overfished and exploited, and more than half of these stocks are thrown away (Fishcoin, 2018). . The frauds have an enduring impact on the profit margins of fishers/farmers who get lower prices for their products due to unsustainable practices (Le et al., 2020).

Thus, the lack of effective tracking and monitoring of seafood products from source to point of sale promotes fraud (FAO, 2017; Tsolakis et al., 2020). Ensuring traceability and transparency along these supply chains is, therefore, a crucial issue which would enhance the profitability of stakeholders (Le et al., 2020). For instance, a fish with a verifiable history can simplify the business operations and selling process for fishermen, distributors, and retailers, especially high-end restaurants and supermarkets, who would pay more for seafood that comes with a verified traceable origin (Rogerson & Parry, 2020). The credibility of seafood labels such as the Marine Stewardship Council (MSC) or Best Aquaculture Practice (BAP), which highlight aspects like sustainability, authenticity, and origin, is tied to traceability (Asche & Bronnmann, 2017; Cook, 2018). Offering a product that aligns with social responsibility can increase profits, strengthen customer loyalty, and create a better brand image for seafood businesses(Asche & Bronnmann, 2017).

1.2.5 Gap in profit share among FASC stakeholders

The opaque FASCs have a detrimental impact on profit margins for fishers/fish farmers against the end retail selling price of the fish/fish product (Purcell et al., 2017). On the contrary, the downstream stakeholders, such as traders, processors, exporters, and retailers, earn a more significant portion, leading to income inequality (Lin & Wu, 2016). Whereas leveraging this lack of visibility in the supply chain, stakeholders such as middlemen, traders and processors often own market information exclusively and maintain exploitative social relations with fisher/fish farmers (Purcell et al., 2017). Thus, the unfair dynamics of the FASC have implications for both social and ecological sustainability on fishers/fish farmers where inadequate financial gains for fishers could trap them in poverty, where they choose excessive fishing as the only way to ensure a basic standard of living (Dash et al., 2022; Haddad et al., 2022). Therefore, examining the economics of fisheries from a value-chain perspective is beneficial for restructuring fisheries to redistribute benefits using efficient operational traceability to enhance transparency in the supply chain, thereby promoting fair distribution of profits among stakeholders. Therefore, the improved supply chain governance and transparent FASCs could improve the profit share for fishers/fish farmers (Førsvoll & Åndal, 2019; Purcell et al., 2017; Blohmke et al., 2019). Producers empowered with such market information with access to some technology would benefit from making better decisions for planning and harvesting to negotiate prices for better profits (Purcell et al., 2017; Rowan, 2022).

1.2.6 Post-harvest supply chain losses

Postharvest losses are one of the significant global seafood supply chain challenges that register huge monetary losses for FASC stakeholders (Dash et al., 2022; Haddad et al., 2022). A study by Abbas et al., (2023) highlighted that the variate average change of postharvest loss and supply chain loss of a fish farmer, processors, traders, wholesalers and retailers are 7.06%, 8.89%, 6.23%, 9.10% and 13.05%, respectively, which notes a substantial financial loss for them, which is also supported by other studies (Béné et al., 2015; De Jong, 2017; Kefi et al., 2017; Kimani et al., 2020; Mulyono et al., 2019). It is noted that seafood loss and waste constitute approximately 35% of the total amount of fish caught

(FAO 2016;Mulyono et al., 2019).Thus, an excellent end-to-end visibility for the stakeholders to avoid post-harvest losses and save the dripping profits of producers.

1.2.7 Non-inclusive sustainability certification

Seafood certification bodies for seafood are increasingly contributing to the enhancement of sustainability and governance in fisheries with no focus on traceability and transparency. Nevertheless, certifications like MSC or BAP have been critiqued for being expensive for small-scale producers (Phong et al., 2021; Purcell et al., 2017). Moreover, traders tend to offer low prices in black-market transactions for certain highly demanded fish species that are strictly regulated under national or international regulations. (Hukom et al., 2019; Jacquet & Pauly, 2008). This shows an economic impact on small and fragmented fish farmers who cannot afford to get their farms certified, which affects the sale of the product and the profit margins (Acharjee et al., 2021).

Thus, to address the concerns mentioned above from FASC, there is a demand for innovative technologies which allow stakeholders, including end consumers, to verify the dynamics of supply processes rather than simply tracing where and when a process occurred. In contrast, BT is a promising new disruptive digital technology that ensures transparency, traceability, and real-time visibility throughout the FASC (Ohler & Pizzol, 2020; Reyna et al., 2018; Sunny et al., 2020).

1.3 Blockchain technology

The occurrence of BT emerged in the crypto-currency domain and was recognised as a disrupting technology (Nakamoto, 2008). The main attraction of this technology is its core functionalities like reliability, transparency, and immutability (Steiner & Baker, 2015; Yiannas, 2018). BT has grabbed the attention of businesses and researchers because of its features to deliver security and data integrity to transactions, real-time visibility, transparency and traceability (Hua et al., 2018; Pizzuti et al., 2014;Bhat et al., 2022; Helo &

Shamsuzzoha, 2020; Yang et al., 2021). The decentralised nature of the stored data reduces the threat of single-point access failure as in the centralised network model (Hoffman et al., 2018). BT uses a peer-to-peer network, which consists of all users (stakeholders) that use nodes to store and share information with connected peers (Pakseresht et al., 2023; Reyna et al., 2018). Therefore, no supply chain member can tamper with the transactions once they are recorded. Thus, one potential solution to the issues and concerns mentioned earlier is the use of BT. This new digital approach, underpinned by Industry 4.0, ensures data integrity and prevents data tampering and integrity that promises end-to-end visibility, trust and transparency in AFSCs.

Definition

BT could be defined as an encrypted digital database which is distributed to all users in the network and consists of data records called blocks (Madumidha et al., 2019; Hald & Kinra, 2019). The data is stored in these blocks in an irreversible and immutable way, which makes them tamper-resistant (Montecchi et al., 2019). Thus, the blocks that form a chain cannot be altered or erased by any user or stakeholder (Kim & Laskowski, 2018; Yli-Huumo et al., 2016). Automated consensus protocols ensure that data transmitted on the network is verified and stored immutably, reducing the risk of data corruption to near zero (Howson, 2020).

1.4 Overview of Consumer Research on BT Adoption

Recent literature has widely explored consumer perspectives on BT-enabled traceability, showcasing the transformative potential of BT across various food supply chains. Studies emphasize BT's ability to provide secure, verifiable records, which significantly influences consumer trust, purchase intentions, and product loyalty. BT has emerged as a strategic tool for enhancing transparency and product authentication, addressing consumers' increasing concerns about food safety, authenticity, and sustainability (Acciarini et al., 2023; Duong et al., 2024)

Blockchain's Role in Enhancing Consumer Trust and Purchase Intentions

One of the major focuses in consumer research is the role of BT in building consumer trust. By facilitating transparency and traceability, BT reduces information asymmetry, which allows consumers to verify product origins, authenticity, and safety attributes (Jiang et al., 2023; Vázquez Meléndez et al., 2024). For example, studies show that Chinese consumers demonstrate higher purchase intentions and WTP for BT-traced food products, especially for categories like pork and tea, where handling practices and quality assurance are critical (Rao et al., 2023; M. Yang et al., 2024). These findings reflect BT's capacity to address consumer trust concerns effectively, particularly for products with complex supply chains or higher risks of counterfeiting.

Studies also indicate that BT labelling on products increases consumer confidence by being a visible indicator of safety and authenticity. Acciarini et al., (2023) highlight how BT labelling meets the growing demand for transparency, suggesting that such labelling supports product integrity and promotes consumer loyalty, making BT an advantageous tool in a competitive food industry. This association between BT labelling and enhanced trust underlines BT's potential to drive positive consumer behaviours, particularly as transparency becomes an expectation rather than a bonus in food markets (Sepe, 2024).

Willingness-to-Pay and Consumer Perceptions of Quality and Sustainability

Several studies suggest that BT's benefits in transparency and traceability positively impact consumer WTP, especially for attributes like quality, safety, and sustainability (Bandinelli et al., 2023; Boukis, 2020). Research focusing on U.S. and European markets shows that BT-traced products with these attributes gain higher prices and greater consumer loyalty. For instance, U.S. consumers in Shew et al., (2021) preferred USDA-certified labels, although BT traceability was valued for its added transparency benefits. Similarly, German consumers appreciated BT's privacy and transparency features but expressed concerns about its complexity and lack of perceived personal advantages (Knauer & Mann, 2020). These mixed preferences underscore the need for clear, accessible communication of BT's unique contributions to product transparency, differentiating it from traditional certifications.

Further emphasizing the sustainability angle, Hina & Islam, (2024) applied the theory of consumption values, finding that BT's features such as traceability, transparency, and immutability, encourage sustainable consumption by aligning with values like trust and social responsibility. BT's ability to verify sustainability claims reduces greenwashing risks, thus appealing to consumers increasingly mindful of environmental and ethical impacts. Studies on BT's role in organic food supply chains reinforce this trend, demonstrating that environmentally conscious consumers prefer BT-backed transparency, aligning with rising demand for credible sustainability claim (Contini et al., 2023; Lin et al., 2021).

Challenges in Consumer Understanding and Adoption of Blockchain Technology

Despite its benefits, consumer adoption of BT faces hurdles related to technology anxiety, complexity, and lack of familiarity. It is observed that technology anxiety restrains the relationship between BT-enabled food traceability systems and consumer trust, finding that while BT increases trust and purchase intentions, high anxiety around technology can weaken these positive effects (Duong et al., 2024). However, there is a need for consumer-friendly BT interfaces and educational initiatives to alleviate concerns, making BT's advantages more accessible and less intimidating(Hakkarainen & Colicev, 2023).

Other studies suggest that consumers might struggle with understanding BT's functionalities and therefore fail to fully appreciate its traceability advantages. Shew et al. (2021) highlight that U.S. consumers often prioritize USDA certification over BT traceability, reflecting a preference for established certifications. Misunderstandings related to BT's association with cryptocurrencies can further cloud consumer perceptions, suggesting that educational initiatives are essential to clarify the technology's relevance and separate it from its digital finance roots such as cryptocurrency(Tsang et al., 2019).

Research also points to demographic variations in BT adoption such as younger, educated, and tech-savvy consumers are more likely to favor BT-enabled traceability, as found in studies conducted in Taiwan and Sweden (Li et al., 2023; and Yeh et al., 2019). Such segmentation implies that marketing strategies need to account for consumer expertise and technology openness. In contrast, studies in the U.S. show that older consumers may need additional information and reassurance about BT's security benefits, which could be addressed through familiar certification partnerships that enhance trust in BT-labeled products (Strebinger & Treiblmaier, 2022).

Consumer Research Gaps and BT Adoption in Shrimp Supply Chains

While BT has been widely studied in various food categories, from beef and pork to organic produce, applications specifically in shrimp production and seafood traceability are underexplored. Research suggests that BT's transparency could be particularly impactful in seafood, where complex supply chains and high risks of fraud require robust traceability solutions(Jiang et al., 2023). Studies on similar high-risk products, such as tea and beef, show that BT-enabled traceability significantly enhances consumer trust and purchase intentions, especially when coupled with certifications that strengthen product quality (Rao et al., 2023; Yang et al., 2024). However, implementing BT in shrimp supply chains presents unique challenges, including educating consumers on traceability benefits specific to seafood, and addressing misconceptions about BT's association with crypto currency.

1.5 Motivations of the thesis

The motivation of this thesis lies in the intersection of BT and FASC with a focus on the Indian shrimp sector. The fisheries and aquaculture sector is one of the critical sectors that contributes to world food security and economic growth (Acharjee et al., 2021; Jennings et al., 2016). However, it is affected by various ongoing challenges that threaten its sustainability. The vital pressing issues, such as lack of transparency (Blohmke et al., 2019;

Cook, 2018), lack of efficient traceability (FAO, 2017; Grecuccio et al., 2020; Visser & Hanich, 2018), Mislabelling and IUU frauds (Bellmann et al., 2016; Lawrence et al., 2022; Young, 2016), excessive dependency on middlemen (BCG, 2020; Mondragon et al., 2020; Reilly, 2018), Unethical and unsustainable catch practices (Cook, 2018), price manipulations (Caputo & Scarpa, 2022; Lagoudakis et al., 2020), lack of an effective recall system in place (Di Vita et al., 2022; FAO, 2020; K. Li et al., 2021), lack of coordination among stakeholders (Callinan et al., 2022; FAO, 2020; Fatema & Uddin-Tuz-Zohra, 2016). Issues like IUU fraud are not only threats to environmental sustainability but also raise consumer health and safety concerns due to contamination and adulteration of products (Cawthorn et al., 2018; Cundy et al., 2023). Additionally, several big organisations have developed their own systems to manage their global operations and direct their suppliers, resulting in opaque supply chain operations that give scope for fraud in the sector(Fox et al., 2018; Pramod et al., 2014). Moreover, the rising demand by consumers to know the authentic information on the origin of products and verify the labels showcases that consumer trust is vital and driven by food production transparency, labour conditions, and social responsibility (Wu et al., 2021;Singh & Sharma, 2023).

On the contrary, BT, with its unique features, promises a potential solution to the challenges in the FASC. As a decentralised and immutable technology, it offers a transparent and immutable, i.e. tamper-proof tool to store transactions and monitor the integrity of information with its real-time data capture capability in the FASC (Kamble et al., 2019; Lezoche et al., 2020). Thus, the enhanced traceability would verify the authenticity and legality of fish products, promoting responsible, sustainable practices in the sector.

However, BT adoption in FASC could not be straightforward and poses some challenges. Thus, firstly, there is a need for an extensive study that explores the existing challenges in the sector, followed by an in-depth analysis of FASC stakeholders' perceptions and thoughts on the need for technical solutions to sector challenges, which also involves their perceptions of BT as this solution. In addition, consumers are the driving force of any supply chain, and it is vital to investigate their perceptions and valuations for BT traceable seafood products to understand the market sentiments on the existing FASC challenges and their effects on consumers' buying behaviours (Di Vita et al., 2022; Nguyen et al., 2015).

This research focuses explicitly on shrimp, which is the most traded seafood product globally. It mirrors the challenges faced by the overall FASC, including highlighted issues of food safety concerns such as antibiotic residues. Despite shrimp being the most popular seafood, it is also the least explored by researchers in terms of its sector challenges. Furthermore, we focused this study on the Indian Shrimp Supply Chain (ISSC), which plays a critical role in the world shrimp trade and is one of the top shrimp producers and exporters in the world, valued at nearly $25 billion in export (BCG, 2020; FAO, 2020). In contrast, ISSC is often in the news with one of its biggest challenges, i.e. the antibiotics residuals identification (De Jong, 2017; Srinivas & Venkatrayalu, 2016; Srinivas & Venkatrayalu, 2016;Handbook of Fishery statistics, 2020). Moreover, a consumer valuation of Indian shrimp was done with the US shrimp consumers, the US being the top importer of Indian shrimp. This study thus investigates the consumer preferences for BT traceable shrimp with the US shrimp consumers.

This thesis aims to bridge this knowledge gap by conducting a comprehensive study in two parts. First, it delves into the expectations and opinions of ISSC stakeholders regarding BT implementation, discussing existing challenges, exploring BT as a solution, and analysing its benefits and costs on adoption. Second, the study investigates consumer preferences for purchasing BT-enabled shrimps through a choice experiment, gauging their willingness to pay (WTP) for BT-traceable shrimps.

1.6 Aim, objective, and research questions of the thesis

This thesis aims to explore ISSC stakeholder views on BT adoption and investigate consumer preferences for BT traceable shrimps. Specifically, we aim to investigate three specific objectives:

1. To examine the existing literature and identify the benefits and costs of BT adoption in the AFSC. To achieve this objective, we will answer the following research questions (RQ):
    a. RQ 1.1. What is the current literature on BT adoption in the agrifood supply chain?
    b. RQ 1.2. What are the benefits of BT adoption in AFSC?
    c. RQ 1.3. What are the costs/challenges of BT adoption in AFSC?
2. To explore in-depth expectations and opinions of Indian shrimp supply chain (ISSC) stakeholders. To achieve this objective, we will answer the following research questions:
    a. RQ 2.1 What are the current challenges affecting ISSC?
    b. RQ 2.2 What are the possible solutions related to challenges in the sector?
    c. RQ 2.3 What are the benefits and costs of BT adoption in the ISSC?
3. To investigate US consumers' preferences for BT traceable shrimp. To achieve this objective, we will answer the following research questions:
    a. RQ3.1 What are the consumer preferences and WTP for BT-enabled shrimps?
    b. RQ 3.2 What factors affect consumer WTP for BT traceable shrimp?
    c. RQ 3.3 Which communication messages affect the WTP for BT traceable shrimps more effectively?
    d. RQ 3.4 What is the consumer's technology readiness and acceptance of BT traceable shrimps?

1.7 Contributions of the thesis

BT as a research field is comparatively in the early stage of its practical implementation, where academic research has recently gained traction. However, the focus of current academic literature on the benefits and costs of BT adoption in FASC remains limited. This thesis, with its twofold approach, holds promise for the ISSC sector. It addresses vast gaps in the literature on both the supply and demand sides of ISSC on BT adoption. It offers a fresh perspective on the stakeholder perception of BT adoption in ISSC, and also explores consumer valuation for BT-traceable shrimp. These pioneering studies, to the best of the author's knowledge, are the first to examine the perceptions and beliefs of ISSC stakeholders on the benefits and costs of adopting BT in the sector, and to investigate consumers' preferences for BT-certified shrimp and measure their WTP. This research, therefore, not only serves as a benchmark for further investigation and exploration on this topic but also paves the way for potential improvements in the Indian shrimp sector.

The Indian shrimp industry, which is one of the top exporters of shrimp to the world, has the potential to use BT to improve its supply chain. It was found that the stakeholders have positive sentiments towards BT adoption to address the current challenges in their business. The study highlights the economic impact of the lack of efficient traceability in the sector, e.g.in relation to the use of antibiotics. Thus, it underscores the requirement of BT-like solutions to ensure traceability to address the pain point in international markets. Moreover, the research provides significant insights into, showing that consumers are willing to pay a premium price for BT-certified shrimps, especially when food safety benefits are highlighted. In addition, it was identified that young consumers from high-income groups and households with children under 18 were remarkably willing to pay premium prices for BT traceable shrimps. Moreover, another unique finding was that the consumers showed a positive sign of acceptance and readiness for BT overall, indicating a promising market for such products.

This research will, in particular, be valuable for the shrimp supply chain stakeholders and policymakers in the industry to understand better BT and how it can improve their ISSC visibility. The study discusses how BT can be vital to improving traceability, transparency, and trust in the industry and share contributions of outcomes for businesses and policymakers as shown below:

1.7.1 For businesses:

First, one of the study's most important findings is that American consumers are willing to pay a premium for shrimp, which can be traced back to the source through BT. Consequently, businesses must begin developing marketing strategies that highlight the benefits of using BT to trace their shrimp products, which will help them stand out and gain more market share.

Second, it has also been found that consumers who read about the food fraud and food safety benefits of BT are willing to pay a premium for BT-certified shrimp products compared to those who do not read any information. This outcome is vital for businesses to create marketing strategies that emphasise their products' end-to-end visibility to show no traces of fraud and the absence of antibiotics. By introducing QR code labels, customers can have access to information about the product's origin, production techniques, sustainability standards, and other relevant data. This would enable them to make informed purchasing decisions and authenticate the product's genuineness, thereby rebuilding trust in the brand and the overall supply chain operations. Businesses must consider using BT as a tool to increase consumer confidence and build brand loyalty.

Businesses must prioritise the implementation of a BT-enabled single platform for all in order to address various existing challenges, such as stakeholder coordination issues, lack of trust, lack of operational efficiency due to lack of visibility, and the issue of middlemen. With BT serving as a single source of truth, businesses can enjoy effortless coordination, communication, and reliable data sharing with end-to-end visibility and transparency, thereby reducing reliance on middlemen to boost profit margins.

By leveraging BT, businesses can make faster and more informed decisions based on real-time and authentic data availability. Furthermore, businesses must invest in capacity building by allocating resources for BT adoption and training employees on the benefits and use of technology for efficient operations and smooth integration with existing systems. This is a critical step that businesses must take to stay competitive and remain relevant in today's dynamic market.

1.7.2 For policymakers:

First, policymakers should recognise the interest shown by both business stakeholders and consumers in adopting BT in the Indian shrimp sector. This represents an excellent opportunity for policymakers to restructure the sector by introducing transparency and trust in the day-to-day business operations to address consumer demand on traceability to ensure about safety of products free from frauds and unsustainable practices.

Second, policymakers must prioritise the integration of BT in the ISSC sector by forming a regulatory framework for BT and acknowledging its potential to enhance accountability, traceability, and transparency in the sector. By upholding ethical standards, discouraging fraudulent activities, and creating more sustainable business regulations, policymakers can build trust among importers, regulatory bodies, and end consumers.

Third, mandatory training should be provided to educate fishers and farmers on modern farm practices, including disease handling and the avoidance of antibiotic use. Government policies must raise awareness of the benefits and costs of BT to promote easy adoption with incentives.

Fourth, policymakers should engage in international collaborations to establish global standards for BT-enabled supply chains, participate in discussions to standardise regulations and facilitate cross-border shrimp trade. This will leverage the end-to-end visibility and real-time immutable data availability of product quality and standards.

Fifth, policymakers should encourage the widespread adoption of BT by showcasing successful case studies in other sectors and advocating for policies that promote BT adoption.

Lastly, policymakers must provide financial support to businesses, such as incentives through tax cuts or grants, to encourage smooth BT adoption. Stakeholders, particularly shrimp farmers and fishers, must be given incentives for smooth BT adoption. This framework will serve both domestic and international demand for shrimp, thereby enhancing the export potential of Indian shrimp.

1.8 Outline of the thesis

In addition to Chapter 1, the introduction, this thesis is organised into six other chapters. Chapter 2 presents a comprehensive literature review of blockchain technology, its applications in the agri-food supply chain (AFSC), fisheries and aquaculture sector, the essential characteristics identified in terms of benefits and costs of the BT, and existing case studies of BT in the agri-food sector. Chapter 3 elaborates on the current status (Trends and challenges) of the Fisheries and Aquaculture sector globally and in India. Chapter 4 illustrates the qualitative study on supply chain stakeholders' perceptions of BT adoption in the fisheries and aquaculture sector with empirical findings and data analysis. Chapter 5 consists of a quantitative study on consumers' preferences and willingness-to-pay (WTP) for BT-enabled shrimp using a discrete choice experiment approach. It also talks about the results of the attributes preferred by consumers and their WTP for these attributes. Finally, Chapter 6 concludes the thesis by summarising the key findings, discussing their implications, and offering recommendations for future research and practical implementation. The implications of the results from this thesis are presented particularly for policymakers and the supply chain stakeholders who are the decision-makers to utilise. At the end of this thesis, the limitations in the research and recommended directions for future studies.

Chapter 2: Blockchain Adoption in Agri-Food Supply Chains: A Review

This chapter is structured in two different sections. First, it introduces blockchain technology (BT) by presenting its history, definition, advantages, and drawbacks. Second, it provides a review of the literature on the adoption of BT in agri-food supply chains (AFSC) with a focus on fisheries and aquaculture, focusing on the benefits and costs identified in the review.

2.1 Blockchain technology

2.1.1 History of Blockchain technology

The history of BT goes back to 1991 when Stuart Haber and W. Scott Stornetta, in their article titled "How to Timestamp a Digital Document", laid the foundation through their early groundwork for what we now identify as "blockchain" (Haber & Scott Stornetta, 1991). Haber and Stornetta, in their pioneering paper, introduced a chain of blocks secured by cryptography to timestamp digital documents, However, the term "blockchain" came later, and their research established the groundwork for the decentralised and tamper-resistant characteristics associated with BT. However, progress in cryptography played a pivotal role in progressing the concepts that would later form the basis of BT (Haber & Scott Stornetta, 1991). Researchers examined methods for securing digital information and ensuring data integrity through cryptographic hashing[1].

Subsequently, Satoshi Nakamoto's influential paper titled "Bitcoin: A Peer-to-Peer Electronic Cash System" in 2008 (Nakamoto, 2008) not only presented Bitcoin as a digital currency but also established the fundamental concept of the original blockchain database.

[1] A cryptographic hash- A mathematical function used in cryptography which involve security properties that combines with the message-passing capabilities of hash functions.

This work introduced the concept of a BT as a distributed and decentralised ledger to record transactions securely and transparently, leading to the first application of BT in the finance sector in the form of Bitcoin (Nakamoto, 2008). BT in Bitcoin was a public ledger for recording all transactions made with cryptocurrency. It essentially tried solving the problem of maintaining the order of transactions and avoiding the double-spending problem (Nakamoto, 2008). Furthermore, in 2015, alternative blockchains beyond Bitcoin emerged, such as Ethereum (Buterin, 2014), which introduced the concepts of smart contracts and started to expand in other sectors such as supply chains, healthcare, agriculture, etc. (Peng et al., 2023).

2.1.2 Smart Contract

BT is often linked with its key feature, the smart contract, which is a set of rules enacted when certain predefined conditions are met (Kosba et al., 2016). The "smart contract" term was first coined by Nick Szabo in 1997 in an attempt to establish a distributed ledger to store contracts among two or more parties (Szabo, 1997). Where a contract essentially means a set of mutually agree d-upon rules or clauses governing the relationship between parties, it serves as the basis for smart contracts (Szabo, 1997; Peng *et al.*, 2023). Smart contracts are the encrypted structure of the information stored in the smart contracts helps to autogenerate transactions without third-party involvement (Khan et al., 2022; Kosba et al., 2016; Majdalawieh et al., 2021; Shahid et al., 2020). This assures the genuine and inclusive nature of the data and executes required transactions (Tripoli & Schmidhuber, 2018). Smart contracts are both immutable and distributed due to their storage within the blockchain, where immutability ensures that the contract code remains secure from tampering, while distribution guarantees the validation of smart contracts' outcomes by participants across the network (Wang *et al.*, 2019; Peng *et al.*, 2023; Callinan, 2022).

2.1.3 Defining blockchain

A blockchain can be defined as a securely encoded, decentralised, and distributed digital ledger across numerous computers (also called nodes) within a public or private network to store data (Burkhardt et al., 2018; Perboli et al., 2018). It consists of interconnected data records, commonly known as blocks. With each transaction, a new block is formed, creating a continuous chain where each block is linked to its preceding and succeeding ones to be called a "blockchain". It prohibits any modifications or deletions of the blocks once they are recorded (Wang, et al., 2019).

As per Wamba et al., (2020) 'blockchain' is a network of coordinating transactions, values, and assets among peers without interaction from intermediaries. It is commonly known as ledger recording transactions. Furthermore, it is defined as a reliable and irreversible digital ledger used to monitor the transaction using a distributed consensus procedure (Kamble et al., 2019). However, 'blockchains' are also described as another application layer that runs on top of the internet protocols that enable economic transactions between relevant parties without requiring a trusted third party (Tapscott, 2016). They can also be used as registry and inventory systems for the recording, tracing, monitoring, and transacting of all assets, whether financial, legal, physical, or electronic (Wang, et al., 2019). It further allows a distributed peer-to-peer network where non-trusting members can verifiably interact with each other without the need for a trusted authority (Casino et al., 2019). Therefore, this enhances the transparency of transactions without depending on explicit trust in a third party but instead relying on the distributed trust established through network consensus. Therefore, leveraging this technology to enhance transparency in the supply chain opens up numerous possibilities (Kayikci et al., 2020).

2.1.4 Advantages and Limitations

Advantages

BT is widely recognized for its potential to enhance transparency, traceability, and data integrity across supply chains, including AFSC and FASC. By establishing a decentralized and tamper-resistant ledger, blockchain aims to minimize risks such as fraud, unauthorized modifications, and lack of accountability in tracking agri-food supply chains including seafood products. Theoretically, these features address key industry challenges, offering an innovative approach to boost trust among stakeholders. However, a closer analysis reveals several practical limitations that may restrict blockchain's ability to fully deliver on these promises in real-world applications.

Transparency

BT's transparency is one of its primary advantages, as each transaction is permanently recorded on a shared ledger, accessible to all participants. This transparency theoretically allows users to independently verify data across food supply chain stages, especially in the seafood industry, where verification of product origin and handling practices is critical (Blaha & Katafono, 2020; Blohmke, 2019). However, transparency alone may not be sufficient to establish trust, as the quality and accuracy of data entries must also be assured. Additionally, data privacy becomes a concern; some stakeholders may resist sharing proprietary information openly. To address this, private blockchains are often used, which, though beneficial for controlled access, may compromise the full transparency of a public blockchain model. In such cases, privacy and confidentiality concerns may overshadow the potential transparency gains, and trust-building efforts may still rely on additional data-verification measures (Galvez et al., 2018).

Decentralisation

Decentralization, a core principle of BT, distributes control across multiple nodes, reducing dependency on a single authority and decreasing the risk of single points of failure. This decentralized structure is particularly beneficial in reducing power imbalances, as it allows multiple stakeholders to participate in data verification, theoretically enhancing resilience and fairness in the supply chain (Zhang & Sakurai, 2020; Burkhardt et al., 2018). In contrast, practical challenges arise, especially within permissioned blockchains often used in private supply chains, where control may shift to a select group of nodes authorized to validate transactions. This setup can undermine blockchain's decentralization, reintroducing elements of centralized control and raising questions of power dynamics. Furthermore, the consensus mechanism necessary in decentralized networks can be slow and costly, complicating governance and decision-making in large-scale implementations.

Ownerless mechanism

A unique advantage of BT is its "ownerless" design, where no single entity controls the ledger. In contrast to traditional systems that rely on a central authority, blockchain operates as a distributed network, where each node verifies transactions autonomously. This ownerless structure is particularly valuable in supply chains, as it prevents any single party from altering or monopolizing information (Rampone et al., 2023). However, this mechanism also introduces challenges in governance and accountability. In permissioned blockchains, commonly used in private supply chains, a select few may gain control over data validation, potentially reintroducing elements of centralization. As a result, power imbalances or conflicts of interest could emerge, diminishing the decentralization benefits that BT aims to offer.

Data authenticity

BT's ability to establish data authenticity is another advantage, as it creates a secure and tamper-resistant record. By enabling untrusted entities to reach a consensus on transaction verification without intermediaries, BT can offer a reliable basis for authenticating supply chain data (Olsen et al., 2019). This level of data authenticity is crucial for maintaining integrity, as any inconsistencies with existing blocks are promptly flagged. However, the accuracy of data input still depends heavily on external data sources (e.g., IoT devices or manual input), and BT cannot inherently verify the initial data's correctness. Thus, while BT can maintain data authenticity within the chain, it does not ensure accuracy at the point of entry, potentially limiting its effectiveness in guaranteeing the true integrity of supply chain data.

Auditability

BT's auditability, through the timestamping of each transaction, enables the creation of an immutable and accessible record. This record supports retrospective checks on transaction authenticity, which is especially valuable in sectors requiring compliance with strict regulatory standards. Such auditability simplifies the tracking of product history, enhancing the trustworthiness of supply chain data (Rampone et al., 2023). However, while auditability provides a secure way to monitor transactions, the volume of data generated in complex supply chains may necessitate additional resources to manage and verify this data effectively.

Immutability

The immutability of BT records ensures that once data is recorded, it cannot be altered or deleted, which is expected to guarantee the integrity of information (Baralla et al., 2019; Cao et al., 2022; Olsen et al., 2019). Although BT can provide immutable records, it cannot essentially ensure the accuracy of the data at the point of entry. For example, in the FASC, crucial information such as the location of catch, compliance with sustainability standards, or storage conditions may still rely on manual entry or IoT devices, both of which are prone to error. Any inaccuracies in these initial data inputs can undermine the reliability of the entire system. For example, if a supplier inaccurately records the handling conditions of fish products, the blockchain's immutability will only serve to preserve incorrect data, potentially compromising product quality or consumer trust.

Disintermediation

BT's potential for disintermediation, or the removal of intermediaries, offers significant cost-saving advantages. By enabling direct transactions between stakeholders, such as farmers, processors, and retailers, blockchain reduces reliance on third parties, which lowers operational costs and enhances supply chain transparency (Motiwala et al., 2021). Disintermediation allows producers to connect directly with consumers, which can benefit smaller farmers by expanding market access and increasing profit margins. Nevertheless, challenges remain; removing intermediaries without a robust technological replacement may complicate coordination, particularly for smaller stakeholders who rely on intermediaries for market information and logistics.

Prompt inventory management

Real-time tracking capabilities of blockchain also contribute to efficient inventory management. BT enables seamless monitoring of product flows, helping avoid issues like overstocking or shortages by providing visibility into stock levels across various supply chain stages (David et al., 2022; Tayal et al., 2021). This real-time visibility can be particularly beneficial in managing perishable goods, yet, implementing such a system requires substantial initial investments in compatible technology, training, and infrastructure, which may pose barriers to widespread adoption.

Efficiency and Cost Savings

Blockchain is expected to streamline operations, reduce reliance on intermediaries, and lower transaction costs. By eliminating the need for middlemen, BT could, in theory, support more direct and faster interactions between producers, distributors, and retailers, especially advantageous for perishable goods, where timely handling is critical (Antonucci et al., 2019b; Callinan et al., 2022; Schlecht et al., 2021). Nevertheless, these efficiency gains are often offset by scalability challenges and transaction costs. Public BTs like Ethereum, for instance, can suffer from high transaction fees and slow processing times during peak usage, which may undermine anticipated cost reductions. Furthermore, setting up and maintaining a blockchain system requires substantial investment. For smaller players, such as small-scale fishers or farmers, these initial and ongoing costs can be prohibitive, potentially limiting the overall efficiency benefits within the supply chain.

Security

BT's decentralized and cryptographic design offers a secure framework, as the absence of a central point of control reduces vulnerabilities to single-point failures. Transactions recorded on the BT are encrypted and distributed across nodes, theoretically making unauthorized alterations challenging. Nevertheless, blockchain is not immune to certain risks. Public blockchains, for example, can be vulnerable to "51% attacks," where a majority control over the network's computing power could compromise data integrity, though this is less likely in larger networks. Moreover, vulnerabilities in smart contracts self-executing agreements coded into the BT can be exploited, potentially resulting in substantial financial losses. Thus, while blockchain enhances security in several respects, maintaining its reliability demands regular audits and updates to guard against emerging threats.

Limitations

Although there is excellent potential for BT to disrupt the current AFSC and its traceability systems, it shows some intrinsic limitations like scalability, privacy issues of stakeholders, substantial initial investment, and the other costs involved that need to be resolved (Wang et al., 2019). However, some critical limitations of BT can be listed and described as follows:

Privacy issues

To use BT to ensure traceability, data needs to be adequately shared among stakeholders (Galvez et al., 2018). This creates concerns about privacy, and data security which might result in inefficient information stored by the partners, resulting in the compromising traceability (Hald & Kinra, 2019), and thus may give rise to poor performance of the overall supply chain. As per Kamilaris et al., (2019) permanent data visibility would compromise the privacy issues of the partners. On the contrary, larger companies might prefer to execute a private and permissioned ledger, which could give rise to oligopolistic practices (Pearson et al., 2019). At the same time, it can be argued that few members in the value chain may be competitors and would not prefer to enjoy the transparency in the system. Thus, it can be argued that if a robust revised structure of the supply chain is to be formed, then crucial stakeholders may have to compromise on their privacy concerns about the relevant data (El Maouchi et al. 2018).

Increase in labour and infrastructure costs

BT implementation involves costs in training staff to enter data and solutions for data storage and management (Takyar, 2021; Xu et al., 2020). While in the longer run, these costs are offset by eliminating inefficiencies and better price of produce, fund allocation needs to be made for initial setup (English & Nezhadian, 2017; Trienekens et al., 2012). The underdeveloped and unorganised infrastructure of the current supply chain involves the high cost involved in implementing BT to bring more efficiency to the system (Wang et al., 2019).

Lack of legal framework

BT, being still in a nascent stage, requires a robust progressive legal policy in the BT-enabled system (Bosona & Gebresenbet, 2013). As a violation or non-performance of the standard contract, are liable for legal proceedings, whereas all transactions in a smart contract environment or framework only run on the goodwill of the participants (Kshetri, 2017). Thus, an absence of any central authority and a lack of censorship features in the system create certain uncertainties. Therefore, it can be argued that this is one of the significant limitations of the BT system (Zheng et al., 2017). Similarly, Lucena et al. (2017) found a debatable problem with the use of BT regarding its legal value. They pointed out that multifaceted agri-food value chain setups in international trade and arbitration laws have yet to be proven.

High-cost problem

As proposed by Lin et al. (2018) to implement BT in the current AFSC, all the stakeholders would need a lot of money and time. The implementation costs involved due to a lack of infrastructure and trained personnel to implement this new technology along with the transportation cost, and adaption costs to train personnel (Meera et al., 2023). Yli-Huumo et al., (2016) highlighted that the more complex the BT becomes, the more computational power it requires, which demands more energy cost to confirm more blocks.

The first data crossover into the BT system

One of the crucial challenges is the quality of the data entering the digitized BT from the real world, where the falsifications in the data at this first step could not be prevented (Creydt & Fischer, 2019). It can hence be observed that in the early stages of the data entrance, manipulation would still be possible, as example, if a food is produced using pesticides but declared as “certified organic” cannot be filtered to enter the BT (Tönnissen & Teuteberg, 2020). The solution to such issues, as suggested by Saberi et al., (2019) could be to perform verification of data using objective analytical methods or by a regular audit of the sites by authorised officials. Hence, these suggestions help avoid the potential smart manipulation at the initial stages of production. BT cannot stop uploading incorrect data (e.g. Garbage in and in-garbage out) where it is simply a data repository (Rampone et al., 2023).

Practical Integrity of Information

While BT offers a strong framework for data security by storing each transaction in a decentralized and immutable ledger, this structure alone does not fully ensure the integrity of the data it holds. The accuracy of information within a BT depends heavily on the correctness of data entered at the outset. Since BT lacks the capability to verify the truth or quality of incoming data, any initial errors whether intentional or accidental are permanently embedded. For example, if data on seafood handling conditions is recorded inaccurately, BT's immutability will maintain this error, which could mislead stakeholders and consumers.

Furthermore, achieving true data integrity often requires complementary confirmation methods, such as IoT sensors for real-time data collection or independent audits to confirm accuracy. In permissioned BT networks, where only specific participants handle data validation, there are additional risks related to potential centralization that could impact information reliability. Thus, while BT can improve transparency and traceability, genuine data integrity relies on accurate data entry, cross-verification, and governance structures to uphold the integrity it promises.

2.2 Literature review

2.2.1 Aim and Objectives

The prime goal of this literature review is to provide an understanding of the current adoption of BT in the AFSC, with particular attention to the fishery and aquaculture supply chain (FASC). This review also attempts to identify gaps in the literature to be investigated in future research. This further intends to gather and analyse a large selection of sources to examine a comprehensive range of BT literature spanning agriculture, food, and fisheries. This study has the following two objectives: (i) to explore in-depth literature on BT adoption in AFSC and FASC and (ii) to explore and identify the benefits and costs of BT adoption in AFSC and FASC.

2.2.2 Methodology

This chapter presents a narrative literature review on the contemporary adoption of BT within the AFSC and FASC. Although guidelines such as the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were utilized to enhance the rigour of the review process, this review does not fulfil the criteria of a true systematic review. Specifically, it did not identify core literature directed at a clearly specified research question but rather synthesized a broad range of studies on the current adoption of BT in relation to the FASC. PRISMA approach helped to visualise the articles selection process, which ensures precision in the review process for others maintaining a structured process, as it requires a straightforward way to the study selection and analysis processes (Moher et al., 2009). The PRISMA methodology offers a systematic framework for designing and executing a comprehensive search strategy on the BT topic literature, considering its rapidly changing nature. Additionally, it confirms that no relevant studies are overlooked.

Given the multidisciplinary nature of the topic, the keywords were entered into four renowned academic databases: Scopus, Web of Science, Science Direct, and AgEcon. These databases were selected because of their comprehensive nature, consisting of many relevant articles and a user-friendly interface to access literature. The study primarily focuses on finding the benefits and costs/challenges of BT in the agri-food sector; the search keywords selected were "blockchain", "food", and "agriculture". After that, a search with keywords "blockchain" OR "digital ledger" AND "food" OR "agriculture" OR "fisheries" OR "aquaculture" AND "supply chain" was conducted. In case of any ambiguity relating to the article's title, the abstract was analysed to determine the relevance of the study. The primary texts of the articles werine also closely investigated, analysing the titles and abstracts against pre-determined inclusion and exclusion criteria (see Table 1) wherever they were required to filter out the most relevant articles for synthesis.

2.2.3 Criteria for Inclusion/Exclusion

To accomplish the purpose of the study, a thorough inclusion/exclusion criterion was set for this review. A clearly defined criterion boosts the likelihood of producing reliable and reproducible results, minimises bias, and protects against drawing poor conclusions (Akella et al., 2023; Rocha et al., 2021). Explicit inclusion and exclusion criteria were set where the results were limited to "peer-reviewed" journal articles only and were also limited to "full-text" journal articles freely available with the institutional log-in. The results were limited to English articles only, whereas only review articles and research articles were included. The selection criteria for the English language only were observed to maintain global exposure to the study and to enrich the depth and inclusiveness of the analysis for a wider audience. Next, this study focuses only on articles published on AFSC to get an in-depth understanding of innovation, such as BT adoption in this sector.

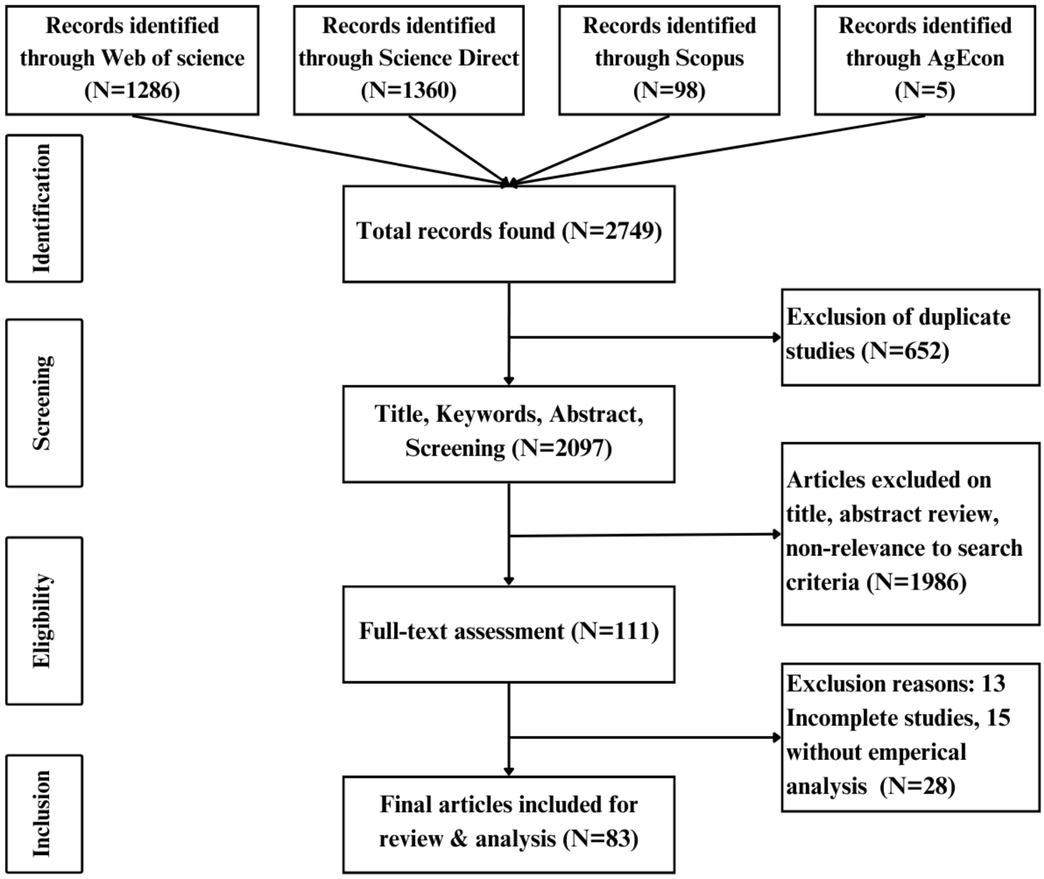
Although news articles, conference articles, book chapters, and white papers provide valuable insights, such grey literature was excluded; however, considering the early stage of the BT research domain, few high-quality conference papers were included too. The time frame of the search was set for the last decade, from Dec 2013 to Dec 2023. The papers before 2013 were excluded because this review study considered the progress of BT adoption and studies from the last decade only. After all, BT is a rapidly evolving technology with significant advancements and innovations that need to be considered to provide a comprehensive analysis of current trends in the sector. Secondly, a 10-year frame allows us to explore these latest advancements considering the discussion of BT in the AFSC sector, which further provides research on BT to mature and showcase contemporary issues and challenges. Moreover, it was only after 2016 that the topic received traction and started gaining pace among academics and researchers.

Table 1-Inclusion and exclusion criteria

Inclusion	Exclusion
Published in English language	Published in other languages
Papers focus on agri-food supply chains only	Papers focus on non-agri-food supply chain sector
Published from 2013 to 2023	Published before 2013
Papers focus on BT	Papers focus on other technologies
Peer reviewed	Business news, magazines, and other

2.2.4 Selection and evaluation

In the first stage of identification, a total of 2749 articles were found from all four databases with applied filters of exclusion criteria such as years of publication and language (English only). Second, in the screening stage, all duplicate articles present across all four databases were removed (652). Next, all research articles' abstracts were assessed, and the articles meeting one of the exclusion criteria were excluded and sorted because of exclusion based on non-matching titles, abstracts, and non-relevance to the topic (1986). Several studies that focused mainly on the technical aspects of BT were excluded, too. However, to get an extensive article selection, the conclusion sections of articles were reviewed when the abstract lacked the information required. The eligibility stage remained with 111 articles for full-text assessment, from which another 28 articles were excluded either with reasons (13) or outcomes (15), resulting in a total of 83 articles (Figure-1). The following section of results includes the review and analysis of the articles selected.



(Source: Created by author)

Figure 1-PRISMA workflow

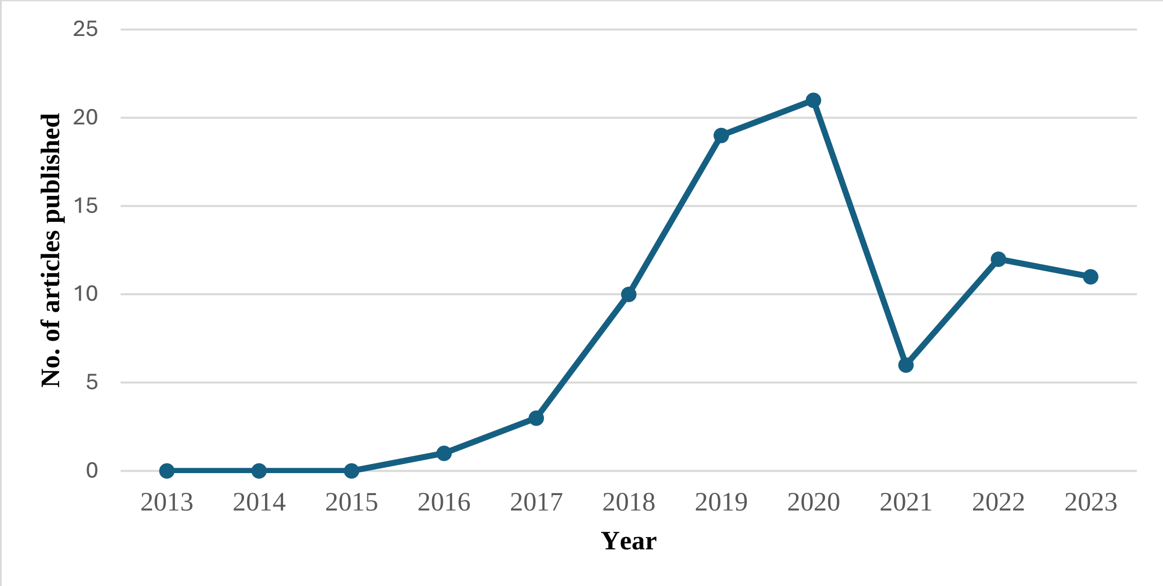
In addition, several other quantitative aspects were analysed, such as a) the number of papers -which describes the volume, depth, and breadth of the literature available); b) geographical location of the research- which provides insights on global research scenario on the topic that identifies the geographic spread of studies; c) authors help to identify critical researchers, institutions, collaborations, etc.; d) methodology of the research- which sheds light on various techniques, approaches, and methods used to study the topic helping to create a base for future studies; e) research objective- which helps identify common themes, and goals in the variety of studies, which also help to develop a framework to understand scopes and synthesis of findings across studies; f) key areas discussed and focused-this helps to find a summary of findings and identify trends, emerging issues, common findings across studies and gaps in the knowledge; and g) the journals they are published in-which shares insights on scholarly affiliations and impact of research based on the type of journals, and categories (Appendix-A).

2.3 Results

This section reviews and analyses the selected articles and elaborates on the findings obtained from them. First, it highlights descriptive statistics of the articles selected based on the year-wise and country-wise application summary. Second, various opportunities and challenges of BT application in the agri-food sector, with a separate focus on fisheries and aquaculture, are presented. Third, the identified benefits and costs of BT adoption are shared. Lastly, various case studies of BT applications are showcased.

2.3.1 Descriptive statistics

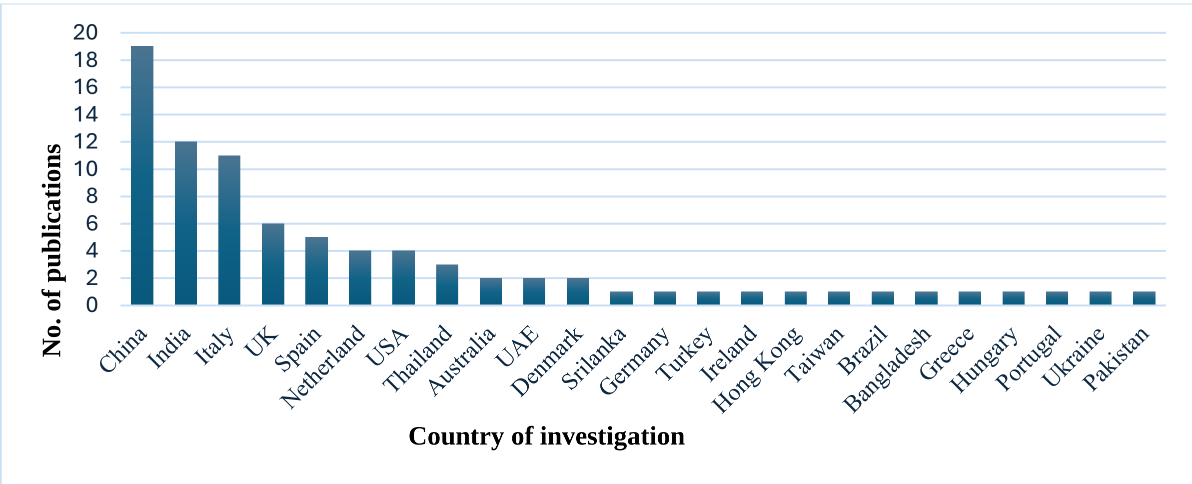
The trend of publication on BT application in AFSC has grown in the last eight years and has increased during the last six years, with a notable jump from 2017, whereas only fewer articles were found between 2013 and 2015, and none were considered for this study. This low number is crucial because it indicates the naïve stage of the research branch. However, the highest peak of articles (21) was noted in 2020. However, a slow but significant growth of research on BT was noted during 2017-2020. The ascending trend shows the emerging interest in BT among academics and researchers. Thus, despite the introduction of BT in 2008 with bitcoin, it took several years for the research community to become fully aware of the potential of BT and its advantages in several sectors, including AFSC. A year-wise publication analysis of the included articles is illustrated in Figure 2.



(Source: Created by author)

Figure 2-Year-wise publication included in the study (2013-2023)

In terms of geographical locations, the highest number of articles identified for this study were from China (19), followed by India (12), Italy (11), and the UK (6) respectively. Figure 3 depicts a complete scenario of the publications by country. The surge in research outcomes in China compared to other countries is a result of the government support for BT and its implementation, technological expertise, higher interest from academics, development of new blockchain research institutions, favourable policy and international collaboration opportunities (Haldane, 2021).



(Source: Created by author)

Figure 3-Country-wise publication of articles

2.3.2 Opportunities and challenges of BT application for AFSC

A review study by Akella et al., (2023) on BT adoption for sustainable agriculture has stressed various enablers such as stakeholder collaboration, enhanced customer trust, and democratisation. On the contrary, they listed the BT adoption barriers, such as a lack of global standards, industry-level best practices, and policies for BT. Similarly, Peng et al., (2023) performed a content analysis and identified four issues, such as agri-food data storage, agri-food information management and control, agri-food data traceability, and agri-food data rights confirmation. They proposed a general framework for BT smart contracts integration in AFSC and further highlighted the advantages, challenges and development trends of BT in the AFSC industry. Whereas, Karnaushenko *et al.*, (2023) studied the adoption of BT in the economic activity of agricultural enterprises, they concluded that BT adoption is an urgent requirement of the modern agricultural economy. However, there are barriers, such as unfamiliarity with BT. They suggested legislative regulation on smart contract applications, creating agricultural cooperatives to reduce the cost of BT adoption, increasing readiness through training for users, developing standards of BT application, and creating business hubs to adopt BT in Agribusinesses collectively.

Researchers Liu and Yu, (2023) constructed a BT e-commerce cold chain traceability model centring on improving the reliability and validity of e-commerce cold chain traceability using stochastic Petri net theory (Petri net is a modelling and analysis tool for distributed systems). They underlined the benefits of the BT traceable cold chain, such as the entire supervision due to high visibility to ensure food safety, joint construction, and governance to standardise the market economic order, reduce the overall costs of the enterprise, and increase farmer income. Moreover, Rampone et al., (2023) noted that overall, BT holds crucial importance in agri-food value chains as it organises and re-engineers the relationships among stakeholders through a technology that supports the disintermediation of the trust. Stakeholders such as consumers, auditors, regulators, and producers are thus authorised to use or create data with a verifiable, auditable, distributed, and independent system, which otherwise is impossible to accomplish. Improved processes with BT would improve business efficiencies with the single source of accurate data shared among all stakeholders.

Another study investigated consumers' preference and perceived value of BT traceable fresh fruit products using the best-worst scaling experiment. Consumers ranked testing information as the most valuable attribute, followed by production inputs (e.g. pesticides), quality certification, and grade information attributes, among which supplier and logistics information were the least valuable attributes. The following four consumer segments were identified from latent class analysis- (a) sensitivity for authoritative information, (b) preferences for comprehensive information, (c) information preferences equally, and (d) preferences for production inputs information (Zhai et al., 2023).

Researchers such as Bhatt et al., (2013) have showcased an Agri-SCM-BIoT (integrates BT and IoT) framework that addressed the issues in centralised traceability systems such as interoperability, storage and scalability concerns, security and privacy issues. They argued on centrally stored databases of current AFSCs, which highlights not only the lack of end-to-end transparency but also the lack of interoperability with little or no coordination among stakeholders in AFSCs. Thus, results show that BT has enormous potential to overcome these challenges using IoT-integrated infrastructures and smart contracts, which will mitigate the challenges of system storage and performance with data security. Similarly, Vu et al., (2022) shared an evidence-driven model for BT adoption in AFSC where the results show the model framework of BT adoption consists of three phases:-a) Initiation (where the firm identifies a need for the technology and defines the scope and plan for the implementation, with a small-scale pilot); b) adoption-where the firm makes the final decision of BT adoption and assigns sufficient resources; and c) Implementation -where the firm prepares for large scale implementation, with integrates it with other stakeholders such as distributors, consumers. At the same time, BT adoption had four determinants:

Technology (relative advantages, compatibility, complexity, and cost), Organisation (resources, readiness, innovativeness, size, and position), Environment (influences from consumers, regulators, and other organisations within the value chain), Management (attitude and engagement from top management). Moreover, a pilot study on BT adoption in the coffee supply chain by Bager et al., (2022) argued that BT is no silver bullet to deliver AFSC sustainability. However, results show that BT could help transform consumer behaviour towards trust-building on product quality and sustainability due to the transparency of information available on provenance.

Furthermore, Kassanuk and Phasinam, (2022) designed a BT framework for ensuring food security and safety and primarily highlighted BT being a solution to the critical issue of the middleman present in the AFSC with the help of features such as authentic data accessibility, security, and immutability. Similarly, Patel et al., (2022) designed a framework for BT adoption in the food supply chain (FSC) where they focused on eradicating the necessity for a trusted centralised authority, and intermediates to make the system more transparent to promote direct interaction among stakeholders. They further highlighted the benefits of BT in AFSC, such as an increase in trust, security, transparency, and traceability of data with enhanced farmer's efficiency and a reduction in food frauds. The authors also added some organisational, technical, and operational challenges to BT adoption.

Besides, researchers Köhler et al., (2022) assessed synergies and conflicts in sustainability standards and BT in AFSC, where they assessed 16 cases of BT-based technologies and voluntary sustainability standards against twelve sustainability-related assessment criteria. The outcomes showed that the relationship between BT-based technologies and voluntary sustainability standards can be co-existing, synergistic, and antagonistic. Whereas a study by Awan *et al.*, (2021) presented a combo model of BT and IoT for the agriculture sector where they claimed the system was reliable, automatic, open, and biological food tracks where IoT devices reduce human intervention and would be efficient in tracking end-to-end food lifespan processes while avoiding massive food wastage, along with identifying and eliminating the foodborne disease causes effectively. This would help customer satisfaction and self-assurance.

Whereas another study by Lin et al., (2021) investigated consumers' intention to adopt BT in organic food products, where they suggest that the adoption of BT is essential in food supply chains to avoid contradictions in consumers about the food safety of products as well as to protect them from counterfeit products in the market. They found that the attitude and perceived behavioural control qualities significantly affected the usage intention in adopting BT, while the subjective norms were positively but not significantly correlated with the usage intention in using BT. Similarly, Hu *et al.*, (2021) invested in the organic food supply chain, it highlighted issues such as data centralisation, monopoly of middlemen, and data asymmetry, which cause a lack of transparency, resulting in reduced consumer trust. Thus, adoption of BT can overcome these issues due to its characteristics such as being tamper-proof, trust-free, decentralised, and immutable. However, it needs to be cared about the costs and efficiency.

Additionally, another work by Chen et al., (2021) explored the adoption of BT in AFSC with a qualitative thematic analysis highlighting the benefits of enhanced traceability and trust throughout the supply chain due to real-time data visibility offered by BT. They further argued that more focus has been paid to the benefits of BT adoption. In contrast, a small number of articles have investigated the adoption processes and challenges, and there is a need for more empirical studies on BT adoption and challenges in the AFSC sector. Similarly, Vu et al., (2021) presented a review and implementation framework for BT in food supply chains. They illustrated BT adoption drivers and barriers, applications, and implementation stages within food supply chains. The authors hypothesised the adoption procedure of BT, such as Initiation, adoption decision, and implementation. Various adoption drivers of BT were highlighted, such as reduction in operations costs, enhanced food transparency and traceability, etc., and barriers such as regulatory issues, lack of expertise in the field, high implementation costs, inaccurate inputs in BT, suitability of BT to the businesses, etc. Issues such as scalability, regulations, privacy, and incentivisation were noted for future research opportunities. Whereas in contrast, researchers such as Treiblmaier et al., (2021) explored the intra- and inter-organizational barriers to the adoption of BT, noting barriers such as a lack of understanding of BT and its potential benefits, absence of management support, lack of oorganisational policies, lack of expertise in BT, and interoperability with other technologies.

Another study on consumer valuation was conducted by Shew et al., (2021) on BT traceable beef using choice experiments, where they shared that although BT shows huge potential to make food traceability more efficient with offered transparency, consumers preferred USDA-certified beef and were willing to pay a premium against BT-certified beef due to limited knowledge of technology. The authors added that BT would incur high costs in the short term, such as implementation, transactional costs, and other infrastructure development costs but would benefit in the long term, which must be noted by potential BT-adopting businesses in the meat industry.

In addition, BT's application in agriculture traceability systems, along with Radio frequency identification RFID tags, highlighted it as a safe information and data management system that shows potential to address supply chain challenges like food fraud and food security, and enhance compliance with regulations, along with better consumer awareness. Thus, this research showcased that using the immutability offered by BT a unique level of credibility (Demestichas et al., (2020). However, some limitations were discussed, too, such as regulations, stakeholder relationships, data ownership, etc. Whereas, Duan et al., (2020) in their content analysis on BT in AFSC, concluded that by combining all the features such as decentralization, security, immutability, and smart contract, BT can eliminate the risks of transactions in a lack of trust environment, which would increase supply chain visibility and transparency, while also improve efficiency, and protect every stakeholder's benefits. However, Rogerson & Parry, (2020) while studying various case studies in AFSC visibility using BT, claim that BT provides visibility of exchanges and reliable data in fully digitized supply chains and provides provenance and guards against counterfeit goods due to transparency. However, there are several challenges to be considered for its adoption in food supply chains, such as lack of trust in the technology among stakeholders, human errors in data handling, food fraud at the borders, governance, consumer data access, and willingness to pay consumers for technology. In similar thoughts, Patelli & Mandrioli, (2020) stressed that although BT shows good potential for efficient traceability, there are still challenges to inadequate knowledge of BT among stakeholders such as farmers and costs. However, BT is noted as a secure, reliable, and transparent tool to ensure food safety and integrity.

Moreover, a BT-based mobile app was proposed by Yadav et al., (2020) to solve a few selected issues of Indian farmers, identified through a profound literature review and the application of the Delphi technique. The mobile app consists of three modules: a) traceability, b) smart contract-based monitoring, and c) information system. Authors thus claimed that the use of BT in the agricultural sector in India possibly will significantly improve the quality of the products offered to the consumers, therefore to the sustainable development of the country. Furthermore, Feng et al., (2020) identified BT characteristics and functionalities, for BT-based solutions to address food traceability issues, and explored the benefits of BT such as information security, data transparency, data sharing, and improved transaction speed, etc., and challenges such as technical, structural, Interoperability and standardization, regulatory, and system performance like storage, latency, and energy consumption. Similarly, Xiong et al., (2020) noted that BT application in AFSC states that the application of BT in the agri-food industry can improve process transparency and efficiency, strengthen trustworthiness, and remove unnecessary intermediaries from the supply chain, besides enhancing the customer's confidence in traceable food products. In addition, Prashar et al., (2020) proposed a BT-based solution that eliminates the necessity of a secure centralized structure, intermediaries, and exchanges of information, optimizes performance, and complies with a strong level of safety and integrity. They made use of smart contracts to examine and operate all communications and transactions within the supply chain network among all the stakeholders. Further, they claim that the proposed model allows a secure and cost-effective supply chain system for the stakeholders that gives a transparent, accurate, and traceable supply chain system.

Moreover, Rejeb et al., (2020) reviewed thoroughly the potentials, challenges, and future research directions of BT, and highlighted the main benefits of BT such as enhanced food traceability, improved coordination among stakeholders, and operational efficiencies of the supply chain. But they also mentioned the potential challenges of BT application in AFSCs such as technical complexity, organizational issues, and regulatory issues. The authors added further that BT could help to increase consumer confidence in the quality, safety, and authenticity of the product and make it easy for provenance data and information integrity of the product. Likewise, another interesting research focused on challenges of BT applications in the AFSCs and classified 18 boundary conditions for food traceability and found that a significant number of these were related to regulatory issues and requirements in the current supply chain and production processes, which require significant organizational changes which then brings more efficiency in food traceability (Behnke & Janssen, 2020). On the contrary, a BT-enabled food supply chain framework was proposed by Kayikci et al., (2020) which focused on the present situation and future opportunities for BT application from the context of emerging economies. They tested challenges such as traceability, trust, and accountability in the food industry using the PPT (people, process, technology) model and noted that customization of current ERP systems in traceability is a major hurdle in BT adoption while the use of IoT devices is required to capture data efficiently.

However, a study by Kamble et al. (2019) shared that BT will bring a paradigm shift in the way the transactions are carried out in the AFSC by reducing the high number of intermediaries, delayed payments, and high transaction lead times. Whereas, the benefits of BT include the broader participation of stakeholders, lower transaction costs, and reduced lead times resulting in increased efficiency due to the most prominent feature of BT are a consensus mechanism. On a similar concept, Baralla et al., (2019) investigated the reliability and transparency of BT in AFSC and proposed a framework of Ethereum-based BT and smart contracts to prevent fraud and to promote the geographical area of the product. The platform helps consumers to check the authenticity of the product with details on both the production chain and supply chain. In addition to this, Basnayake & Rajapakse, (2019) presented a design framework for BT adoption in the organic food supply chain where they aimed to implement BT based solutions to verify food quality and provenance of organic food products. The public BT concept was used along with developing smart contracts to exchange product ownership throughout the whole supply chain network. Results showed trust built among stakeholders due to transparent transactions on smart contracts. Moreover, the implications and challenges of BT adoption and its effect on the AFSC were explored by Kamilaris et al., (2019) where the key challenges discussed were governance and sustainability of BT, policy and regulation rules, technical challenges, and design approach of frameworks to address success acceptance of BT globally. Whereas, Scuderi et al., (2019) investigated BT integration to safeguard POD and PGI labelled products such as blood oranges from Italy who shared that BT helped to reduce the information asymmetry in the supply chain along with increased direct inter-relations among producers and consumers, and guarantees food safety, with an efficient track and trace of products.

However, a review of the application of BT in the agri-food sector suggests that BT can benefit food security due to the transparency, low transaction costs, and interoperability offered by the robust decentralized technology, however, is still immature to scale and difficult to apply due to the complexity (Antonucci et al., 2019). Similarly, a study by Surasak et al., (2019) argued that the BT database coupling with IoT gives several benefits to our traceability system because all of the collected information is in real-time and kept in a very secure database which cannot be manipulated by a human. With the implementation of the BT database, all true value is kept directly in the database without changing, which leads to high reliability of the system. Similarly, Borrero, (2019) investigated AFSC traceability using BT to assure consumers about the origin of the products as all the data and transactions carried out in the chain are recorded in the BT and managed through a smart contract. The BT-enabled system is thus efficient, safe, and transparent and also avoids intermediaries, which lowers costs while generating greater confidence in all stakeholders. On similar notes, Creydt & Fischer, (2019) presented a study on BT algorithm-based traceability for AFSC where they concluded that the BT implementation along with IoT approaches, because of promising transparency and visibility and reduces food adulteration and increases food security and integrity thus BT can revolutionize the food industry. However, the authors have stressed some challenges that need to be addressed such as sensitive data handling and digital storage capacity along with required standards for implementation, especially by SMEs would slow down the BT adoption speed. On the contrary, Yuxin and Xu, (2019) proposed a smart agriculture model based on BT-enabled traceability with the use of wireless sensor network on Ethereum. They claimed that BT features such as decentralization, transparency, consensus, trust, and security would efficiently ensure the safety and reliability of agricultural products through traceability information and also cut the product traceability cost of agricultural systems.

A new simulation model for agriculture tracing implementing BT and multi-agent systems was proposed by Casado-Vara et al., (2018). They concluded that the BT BT-based model is better than the traditional agriculture tracing model as in the decentralised AFSC, each stakeholder can write their transactions on the system through a smart contract, and each of them can buy and sell products with all member's inclusive participation in the supply chain activities. Additionally, another BT-based traceability system (i.e. AgriBlockIoT) was developed by Caro et al., (2018)for the AFSC, suggesting a fully decentralized system in which IoT devices using two different BT implementations (i.e., Ethereum and Hyperledger Sawtooth) which allows food traceability with food safety using smart innovations on digital data. They further compared and analysed the BT implementations assessing their performance in terms of latency, CPU, and network usage, and stated that Ethereum showed greater performance than Hyperledger Sawtooth. Moreover, Sander et al., (2018) investigated the acceptance of BT in meat traceability and transparency and found that consumers find the amount of information on certification labels as complex and get overwhelmed by the amount of information. Thus, BT implementation shows significant positive impacts on consumers' purchasing decisions based on quality perceptions of meat products. Additionally, authors such as Galvez et al., (2018) primarily focused on future challenges in the use of BT for food traceability analysis where they stressed solving food frauds and tracking sources of contamination using BT through storage of chemical analysis data (digital footprint) on BT to benefit with transparency, authenticity, efficient traceability, food security, and safety.

Whereas, Ge et al., (2017) explored BT application in the food supply chain and reasoned that in the agri-food sector, smart contracts could play an important role in automating the role of governing bodies and information exchange interactions, however, there are rising concerns regarding the quality of the legitimacy of reported data, and consistency of smart contracts. Moreover, thus BT offers a chain of records and a trust building mechanism among supply chain stakeholders. However, researchers like Tian, (2016) studied and analyzed the use and development of BT and RFID in the AFSC traceability system which helps the markets to enhance food safety and quality and reduce food losses during the logistics. They evaluated products such as fresh fruits vegetables, and meats for this study and found increased authenticity of the food safety and quality. The same author Tian, (2017) developed a traceability system called BigchainDB, a food supply chain based on BT and IoT(e.g. RFID wireless sensor network (WSN)) for real-time food traceability based on Hazard Analysis and Critical Control Points (HACCP), where all stakeholders could benefit from openness, transparency, objectivity, reliability and safety. All physical products were linked with a virtual identity using an RFID tag.

2.3.3 BT adoption in fisheries and aquaculture supply chains (FASC)

A BT traceable framework for the aquaculture supply chain was presented by Luna *et al.*, (2023) using smart contracts, which adds benefits such as it allows producers to improve their compliance with the set of requirements while maintaining efficiency, profitability, and global competitiveness, in organic aquaculture, using fraud prevention. Whereas, Thompson and Rust, (2023) examined the social, cultural, and institutional factors that affect easy adoption of innovation to digital technology in FASC using theories such as innovation resistance theory, principal-agent theory, and the theory of planned behavior. They suggested that decentralization and information sharing by BT could affect the competitive advantage of wholesalers, as it would change existing asymmetries around trade, price, and provenance information in the sector. On the contrary, barriers to BT adoption in seafood exports were investigated by Meera et al., (2023), which includes regulatory uncertainty, lack of regulatory compliance, and higher implementation costs which need to be reduced for better adoption of the BT. They further noted that consumers can absorb these costs as part of value addition in the value chain. Similarly, Mileti et al., (2023) explored the application of BT and issues related to it in the aquaculture sector to enhance possibilities of sustainable FASC and circular economy, with a better relationship with stakeholders including consumers. Results confirmed that although BT has potential solutions for sustainability and circular economy, it is essential to consciously bring all stakeholders from aquaculture farms to retailers and consumers to access common benefits.

Whereas, Patro et al., (2022) designed a solutions architecture and proposed a secure and trustworthy private Ethereum BT-based solution to efficiently manage the FASC operations in a decentralized, transparent, traceable, secure, private, and trustworthy way. The authors compared their proposed solution with the existing BT and non-BT-based solutions to demonstrate its efficiency and novelty. On a similar note, Khan et al., (2022) shared a public-private hybrid conceptual framework for BT in the shrimp supply chain, named as ShrimpChain which addresses the traceability through the supply chain entered by the associated stakeholders via mobile/web app or Internet of Things (IoT) devices to the BT network. They claimed that BT ensures high production standards, and restricts contamination threats, with wide visibility throughout the supply chain enabling all the stakeholders to assure and certify the data. However, they have added that the costs involved for such a framework are minimum, added as another benefit of BT.

Moreover, researchers such as, Callinan, (2022) conducted a systematic review to identify enablers and barriers of BT in FASC. The author identified BT enablers such as resources, government, support, visibility, business, and management, whereas also highlighted BT adoption barriers such as integration, regulatory, costs, stakeholders, legal, complexity, scalability, uncertainty, interoperability, technology, infrastructure, and expertise. In a similar way, Olsen et al., (2022) discussed the use of BT in the seafood industry in terms of its application, benefits, and costs. They highlighted various improvements brought by BT in the sector as compared to the traditional supply chain such as enhanced supply chain efficiency, improved brand trust among consumers, food safety due to transparency, sustainability due to the end-to-end visibility of the product, reduced number of food frauds, food waste management, etc. They conclude that BT is a good solution to the fishery supply chain due to the suitability of data sharing among stakeholders and interoperability, with the provision of a better overview for better management of the supply chain. However, in a review of the current status and prospects of BT application in FASC Tolentino-Zondervan et al., (2022) found that BT adoption must address suitability, incentives, and trust factors in the sector whereas, as prospects, BT-enabled projects could better utilize to explore the full potential of BT and IoT in data collection to improve quality and trust in data capture. Whereas another study explored the role of various digital technologies such as BT, IoT, and cloud edge computing to bring sustainability in FASC through mitigation of diseases, waste reduction, increased production, etc. The results show a vast potential in the use of technologies such as Artificial Intelligence (AI), Machine learning (ML), and BT for an efficient FASC (Rowan, 2022).

A case study on BT implementation in the Thai fish industry was conducted by Tsolakis et al., (2021) with the aim to address the United Nations Sustainable Development goals (SDGs). The results showed a presence of data asymmetry among stakeholders, for which they developed a BT implementation framework, whereas the authors concluded that this framework would impact fisheries supply chain resilience due to BT to achieve SDGs. Additionally, authors such as Howson (2020) on BT adoption for sustainable marine management, explored a new approach to bring transparency in FASC through resourcing and fundraising for healthy oceans. The results show that BT could be a good enabler of trust and a transparent system for marine conservation global seafood production networks, and charitable donors unless all stakeholders are given a fair share and the issue with garbage in-garbage out i.e., authenticity of first data input on the chain is taken care off. Whereas, Cruz & da Cruz, (2020) in their study focused on Etherium-based BT adoption in fishery value chain traceability. They proposed registering all supply chain activities in a distributed, transparent, secure, and trustful manner using smart contracts to identify the lot number. The results drawn show that BT enables the FASC to become more transparent, and thus improve its reputation and earn credibility with improved consumer confidence. Furthermore, BT infrastructure for fish farms for agriculture data integrity was explored and built by Hang et al., (2020). This infrastructure aimed to provide secure storage to preserve large amounts of supply chain data from manipulation. They used a proof-of-concept mechanism that integrates a fish farm system with the Hyperledger Fabric (permissioned ledger) BT for enhanced security.

A highly insightful report on BT application in seafood value chains was published by Blaha & Katafono, (2020). They have elaborated in detail on traceability in fishery value chains, smart contracts, and the role of BT in compliance at different levels of value chain custody (e.g., flag state, coastal state, port state, processing state, and end market state). The authors have underlined barriers in BT adoption among which regulatory uncertainty, lack of trust among users, lack of coordination in the network, etc. were some of the key challenges. The costs involved in BT development or subscription and technical infrastructure requirements were discussed. However, Aich et al., (2019) underlined the disparity between the traditional supply chain and IoT-integrated BT supply chain and presented a case study on the fishery supply chain with IoT-integrated BT supply chain. The IoT integrated BT enabled supply chain system was found to be more efficient and trustworthy than the traditional one, whereas the case study on the seafood industry highlighted several benefits of integrating BT into the network with better results such as better food quality and security, increased consumer trust, reduced number of frauds and operating costs too. Similarly, Mathisen et al., (2018) have discussed the application of BT in Norwegian Fish Supply Chains. BT was observed to mainly impact the quality, cost, and sustainability aspects of operations. BT is expected to increase the detail in control of product flows in supply chains with a reduction in costs.

2.3.4 Benefits and Costs of BT adoption

This section discusses the various characteristics of BT identified from the reviewed literature which are divided in the form of the benefits and costs of BT in AFSC, which subsequently builds a base for the following studies and chapters of this thesis. Numerous advantages are identified in the AFSC such as enhanced trust among the stakeholders and consumers, security, transparency, and traceability of data, better coordination among stakeholders, efficiency in recalls, and improved food safety. One of the crucial advantages of BT identified for both stakeholders and consumers is traceability which generally refers to the "ability to identify and trace the history, distribution, location, and application of products, parts, and materials, to ensure the reliability of sustainability claims, in the areas of human rights, labour (including health and safety), the environment and anti-corruption"(UNGlobalCompact, 2014).

in this section, the characteristics of traceability in benefits are grouped further divided into five categories such as supply chain benefits, consumer/market benefits, regulatory benefits, foods safety and quality, and risks and recall benefits, and costs are divided into two categories such as implementation costs, and operations costs which were. In line with a study by Asioli et al., (2012)

Benefits

Supply chain benefits

Supply chain benefits identified from the literature include enhanced traceability (Baralla et al., 2020; Patro et al., 2022; Liao and Xu, 2019), transparency of the product (Golosova, 2018; Rogerson & Parry, 2020; Thakur & Breslin, 2020), an increase in trust among stakeholders in the AFSC (Garrard & Fielke, 2020; Golosova, 2018; Howson, 2020; Robinson et al., 2020), a reduction in costs(David et al., 2022; Mai, Bogason, Arason, Árnason, et al., 2010; Tayal et al., 2021), and better coordination among the stakeholders (Dey & Shekhawat, 2021; Hastig & Sodhi, 2020; Lehmann et al., 2012) moreover trust is a significant predictor of any supply chain's performance that improve coordination among stakeholders (Tan & Saraniemi, 2022). The transparency offered by BT is one of the most discussed key characteristics of BT, as it shares credibility of the information shared, and thus a digital food supply chain powered by BT would permit full transparency so that consumers, retailers, manufacturers, and suppliers all have confidence and trust in the companies that they purchase and consume their food from (Kamble et al., 2020). Furthermore, a study by Patel et al., (2022) on BT application in the food supply chain shown that BT increases trust, security, transparency, and traceability of data. Researchers such as Cruz & da Cruz, (2020) highlighted that the use of BT adoption improves coordination among the supply chain stakeholders which allows the efficient handling and measuring of the quantity and particular wild-caught fish species. Furthermore, BT could build good trust among stakeholders due to better visibility in the AFSC (Behnke and Janssen, 2020). Whereas, other benefits such as reduction in costs such as transaction cost, quality cost, time cost, activity cost, and supply chain traceability additional cost in the AFSC were identified (Kayikci et al., 2020; Xu et al., 2020).

Consumer and Market benefits

It has been observed that among the market benefits,(Tan & Saraniemi, 2022) providing information on the food's origin businesses can assure food safety, reduce food fraud, and hence improve brand status (Khan et al., 2022). Similarly, researchers such as Xiong et al., (2020) shared that BT shows a good ability to track the provenance of food and improves trust in AFSC to build confidence and better relationships of businesses with their customers. In addition, a study by Xu et al., (2020) highlighted that BT-enabled traceability helps food safety and would build market and consumer confidence and improve brand reputation, along with making a better supply chain management, and reducing liability risk.

Similarly, Lin et al., (2018) describes that when consumers and supply chain partners know that brands are transparent about the quality and origin of their foods, it builds brand equity and trust, creating differentiation. By tracking each step of the food supply chain and sharing data on an immutable ledger, participants can ensure the promised quality of goods is unquestionable. One of the major benefits of BT is that it ensures the food producers that the quality of their supplies is intact in the supply chain and the fraud identification would be notified immediately to the retailer due to its transparent system.

Global food risks and recall incidents such as the Europe 2013 horse meat scandal in the UK, a food labelling fraud, and multi-state Salmonella outbreak in the US (2017) caused by Maradol papayas, and contaminated egg scandal in Switzerland, Hong Kong, and 15 EU states in the same year (Chen et al., 2020) raised concerns on food authenticity among end consumers. Current food traceability supply chains do not offer end-to-end transparency of the source of the product; therefore, in case of a food safety incident, the seller is unable to identify the exact source of contamination (Xu et al., 2020). Thus, BT offers a great help to calm down the food recalls and lower the negative publicity of quality and safety events in the whole sector due to its real-time data provision including the exact source of the food contamination within seconds. However, efficiently tracing the source for the removal of contaminated products instead of recalling the entire product is still a large issue both socially and economically. Thus, BT promises to efficiently recall the food products in cases (Galvez et al., 2018; Kayikci et al., 2020; Rogerson & Parry, 2020). Thus, better traceability methods with BT would help in reducing the production and distribution of unsafe or contaminated food, thus decreasing the possibility of bad publicity and food re-calls Food Safety and quality benefits (Motta et al., 2020). It has been critically argued that the exponential rise in food adulteration cases has caused huge monetary losses to the companies, and thus a substantial decrease in the trust factor of customers has become a big hurdle in the food supply chain. (Galvez et al., 2018). Moreover, a lack of food safety risk crises makes consumers living in an asymmetric of food information in the food supply chain, which create high risks (S. Xu et al., 2020; Zhao et al., 2019). Researchers like, Mondal et al., (2019) have too discussed the issue of food contamination being a major challenge in the AFSC, which demands the need for a reliable and trustworthy tool to check the state of products throughout the value chain. Therefore, they suggest that BT has good potential to expose geographic and biological origin publicly and would be a powerful tool to prevent food fraud enhancing trust in the system. Furthermore, BT helps to gain consumer confidence, with the promised safety and quality of the food. For instance, a study by Tse et al., (2018) has examined the relevance of BT in the economic, socio-cultural, and technological (PEST) analysis for the AFSC in China. They claimed that all transactions recorded in BT were transparent and all nodes could trace food data like where the origin of the food, to assist the businesses in improving the food safety (Khan et al., 2022; Köhler & Pizzol, 2020; Tsang et al., 2019; Xiong et al., 2020). Therefore, the transparency in the supply chain offered by BT helps to keep an end-to-end track of the activities throughout the supply chain, whereas being immutable no manipulation of data occurs that keeps the food safety information intact (Bager et al., 2022; Chen et al., 2020; Song et al., 2022; Tian, 2017). However, several researchers have explored the use of a combination of IoT and BT together to enhance food safety through traceability efficiency, as the use of IoT devices/sensors to capture data reduces complete manual interference. A study by Bumblauskas et al., (2020) tracked the eggs from farm to fork using BT and IoT-enabled technologies, and stated that the results indicated that BT can be utilized and applied to move goods more efficiently and transparently through AFSC which diminishes the risk and cost of food recalls, fraud, and product loss, and importantly this would build strong consumer relations with the businesses due to traceable and transparent supply chains.

Likewise, Patel et al., (2022) added that BT improves quality control and food safety due to transparency obtained due to complete visibility in the AFSC. Similarly, Aich et al., (2019) stressed that the BT-based systems offer an enormous benefit to all the stakeholders; as food producers would ensure that the quality of their supplies are not getting altered in the supply chain and the immediate fraud identification notification the retailer would get due to the transparency in the system. Whereas, on the retailer side it would be easier to trace the spoiled or damaged food product without checking the whole supplies. Eventually, the end consumer would benefit by being able to know what quality food they are consuming. Thus, the immutable nature of the BT offers a new opportunity, which would curb the data manipulations and could be identified easily the source of it, making the overall system more transparent and robust (Casino et al., 2019).

Regulatory benefits

Another characteristic of BT discussed in regulating the AFSC was smart contracts. Smart contracts can be described as a set of programming instructions to generate complex transactions between two trade partners using a decentralized BT (Francisco & Swanson, 2018; Motta et al., 2020). Any player in the AFSC could generate a contract with other businesses in the AFSC by placing a transaction to the BT. When the contract is generated, the code of the program of a contract is permanent, and thus could never be changed. Smart contracts prevent highly confidential data from cyber-attacks (Kamble et al. 2020; Xiong et al., 2020) and thus, could play a crucial role in data security. Lin et al., (2018) mentioned that existing IoT-based provenance and traceability methods for AFSC are built on a base of centralized frames, leaving a scope for unresolved concerns which include data integrity, single points of failure, and tampering issues. Therefore, the authors proposed a framework based on the BT Ethereum platform to develop smart contracts, combining RFID technologies to capture the data to safeguard the traceability system using smart contracts offered by BT. Kumar & Iyengar, (2017) in their study on a BT application in the rice supply chain, recommended a system smart contract-based application to help regulations among the partners in the supply chain to prevent food fraud. They added further that the main issue was related to fraud in the supply chain, and thus decentralized BT, despite an absence of governance by any central authority, seems like to be the solution to the problem. Researchers have also discussed the end-to-end visibility offered by BT to help government and other regulatory bodies for allocation of apt resources (e.g. cold storage) and keep an eye on the right amount of tax collected from and providing subsidiaries to the stakeholders wherever required (Khan et al., 2022). However, Xiong et al., (2020) claimed that when BT is jointly used with smart contracts, it allows timely payments between stakeholders that can be triggered by data changes appearing in the BT. In addition, Salah et al., (2019) exploited the potential of the Ethereum BT and smart contracts for soybean supply chain tracking and traceability. The proposed framework permits trade execution, without intermediaries or trusted centralized authorities. The authors described the system architecture, the entity-relation diagram, the sequence diagram, and the algorithms which is the base of the proposed model. Advantages like integrity, security, and reliability are mainly highlighted in this research.

Similarly, Mao et al., (2018) investigated a BT-based credit evaluation system to strengthen the effectiveness of supervision and management in the AFSC. The system proposed here assembles credit evaluation text from traders by smart contracts on the BT. Then the gathered text is analyzed directly by a deep learning network named Long Short-Term Memory (LSTM).

Costs

The introduction of a traceability system incurs various costs including hardware costs, software costs, operations costs, and labour costs. These costs can be divided into implementation and operations costs (Xu et al., 2020). The implementation costs include hardware costs such as devices, computers, terminal query equipment, barcode readers, etc., and, software costs such as the development and deployment of software, building of a supply chain system communication system, equipment depreciation costs, and other human costs such as hiring technical personnel, and other staff's expenses costs such as salaries. Whereas operation cost refers to the cost that involves the maintenance of the normal operation of the whole system, including recall cost of faulty products, product marketing and publicity expenses, and communication and coordination expenses with other parties in the system (Schmidt & Wagner, 2019). Furthermore, a study by Ray et al., (2019) mentioned that along with several benefits of BT in AFSCs, several costs such as onboarding costs for BT in the new system (including both operations and maintenance), infrastructure and network requirement costs, data storage cost per transactions are essential to be considered. Nevertheless, there are negligible studies available on the actual implementation of BT in AFSC. However, it is observed that the businesses would need to incur higher implementation of BT, and it won't outplay its benefits (Zhao et al., 2019). Moreover, the complex structure of BT would demand considerable time and resources for businesses to master this novel technology, and meanwhile, the cost of hiring BT experts would be remarkably high due to high demand. Additionally, businesses are required to invest in hardware such as RFID tags and other IoT sensors (Chen et al., 2020). Many big firms such as Walmart being financially capable have invested in BT projects to gain rewards in long-terms, but small businesses and farmers would find it difficult to make such huge investments causing a major hindrance to BT adoption the AFSC (Xu et al., 2020; Zhao et al., 2019).

While the literature agrees that BT would disrupt the current supply chain practices, this technology noticeably presents many challenges that need to be addressed by future researchers in the domain. Challenges include mainly concerned with the need for data standardization in the agrifood domain, governance strategies, and technology development to cope with a large dataset (scalability) (Pearson et al., 2019). Similarly, Tian (2017) who has also focused on challenges to adopting BT in the future supply chain traceability systems stated that BT being in the early stage has scalability issues in terms of throughput, latency, and capacity when facing mass data in a real business environment. Additionally, other challenges of BT applications such as high implementation cost, privacy, storage, energy consumption, latency, and interoperability were highlighted (Awan et al., 2021).

The security infrastructure of BT faces major challenges. Today, although a groundbreaking advance is seen in BT as a novel approach in decentralised information technology, this technology is at premature stages (Tian, 2017). Despite the promises offered by the BT, it has some intrinsic flaws, among which scalability is a prime and vital one, due to the handling of mass data in the real-world scenario (Behnke & Janssen, 2020). Thus, although it will be connected to the BT network, and the data remains immutable, an investigation is required on the verification mechanism at the input stage, if the raw data was authentic and correct. If someone still, tries to tamper the data using sensors, the BT cannot detect it (Lucena et al.,2017). By these findings, relevant research demonstrates that even with the developing reputation of BT, its implementation remains in the early stage, since available use cases lack solid claims of its effectiveness and credibility (Mirabelli & Solina, 2020; Tian, 2017). However, the classification of current BT use cases proves sector-specific concerns which suggest future directions for further research. There is, however, a lack of study on actual costs such as implementation (e.g., development, deployment, integration with existing software, etc.) and maintenance/operations costs (e.g., updates, training, audits, labels & packaging, etc.) of BT adoption in AFSC (Khan et al., 2022; Patelli & Mandrioli, 2020; Tsang et al., 2019; Xiong et al., 2020). Thus, future studies can evaluate the proposed BT-based traceability framework effects from different perspectives, such as implementation costs, maintenance/operations costs, storage capability, and the overall efficiency of agri-food value chains (Tripoli & Schmidhuber, 2018).

Therefore, the literature reviewed portrays the benefits and costs of BT adoption in AFSC. The next section discusses several case studies and ongoing projects identified during the review of various literature on BT adoption in AFSC.

2.3.5 Consumer research studies on BT adoption

BT has gained significant attention in food traceability to enhance transparency, trust, and consumer confidence (Vazquez Melendez et al., 2024; Zhai et al., 2023). Studies highlight BT's role in reducing information asymmetry and improving purchase intentions through features like tamper-proof records and QR codes. While its benefits are evident, challenges such as technology anxiety, complexity, and limited consumer awareness remain barriers to adoption (Fan et al., 2022; Strebinger & Treiblmaier, 2024). This section reviews key research on BT adoption starting from recent to older, exploring its impact on consumer trust, willingness to pay, and behaviour across various industries, focusing on strategies to overcome these challenges and maximize its potential.

Similarly another study by Duong et al., (2024b) applies the stimulus-organism-behavior-consequence framework to analyze BT's impact on trust within organic food supply chains. They suggest that BT enhances trust in organic food producers and retailers, thereby improving purchase intentions, word-of-mouth, and repurchase intentions. They also note that congruence between producer and retailer trust further enhances consumer loyalty which is a good sign for BT adoption.

Shahzad et al., (2024) examined how BT influences consumer trust and willingness to pay more within mobile food delivery applications (MFDAs). They argue that BT's transparency, traceability, and privacy features positively impact consumers' perceived value, leading to greater adoption intent and increased willingness to pay. However, while their analysis emphasizes BT's role in addressing privacy and trust issues in MFDAs, it could benefit from discussing potential integration challenges within existing platforms. In addition, MFDAs should consider incremental BT integration, particularly for sensitive data sharing, to enhance consumer trust gradually without information overload for the consumers. Whereas, Vázquez Meléndez et al., (2024) provided a systematic review of BT's application in supply chain management, focusing on enhancing product provenance, efficiency, and consumer trust. They discussed BT's role in providing secure, tamper-proof records that facilitate traceability, particularly in high-stakes sectors like the food industry. By incorporating physical product fingerprinting, BT enables stakeholders to verify product authenticity, reducing counterfeiting risks and enhancing consumer confidence.

Furthermore, Vázquez Meléndez et al., (2024) examined Australian consumers' willingness to pay (WTP) a premium for BT-certified food, emphasizing the significance of food provenance and data security. The authors concluded that BT's transparency and traceability features foster consumer trust, with gender differences indicating that females prioritize transparency more in their purchasing decisions. Similarly, Hina & Islam, (2024) investigated how BT affordances, such as transparency, traceability, and immutability, influence consumers' sustainable consumption intentions. By applying the theory of consumption values, the authors find that these affordances positively impact values like trust, social impression, and sustainability clarity, which in turn increase the likelihood of consumers purchasing sustainable products.

Sepe, (2024) researched how BT technology in food label systems impacts consumer purchase intentions using the Unified Theory of Acceptance and Use of Technology (UTAUT) framework. The findings indicate that perceived trust and product transparency significantly enhance purchase intentions, especially among younger demographics that effectively demonstrates BT's role in fostering trust through transparent labeling, a focus on older consumer segments might enrich its implications. Reitano et al., (2024) in their systematic review explores factors influencing consumer acceptance of BT in agri-food, particularly in terms of trust, safety perception, and willingness to pay (WTP). The authors emphasize that transparency and reduced risk perception enhance trust, which in turn bolsters WTP for BT-tracked food products.

Whereas, Strebinger & Treiblmaier, (2024) studied whether BT can fully disintermediate consumer services by removing traditional intermediaries and shifting trust directly to the technology. Their findings suggest that while BT enables disintermediation, consumers often prefer re-intermediated services that include support features such as customer assistance and data privacy options. Privacy concerns increase as consumers become familiar with BT, leading them to favour well-known brands over startups for enhanced data security. Similarly, Tran et al. (2024) analyze how Greek consumer ethnocentrism affects attitudes toward BT traceability for Feta cheese, revealing that ethnocentric consumers are more willing to pay for BT-backed traceability, especially when supported by QR code information. This suggests that patriotic marketing and accessible information channels could strengthen consumer engagement with BT-based systems.

Furthermore, Yang et al., (2024) assessed consumer preferences and WTP for BT-based traceability systems for fresh pork in China. Their results shown a higher WTP when BT traceability is coupled with government certification, underlining the importance of trusted certification entities. They further highlighted the value of BT in enhancing food safety perceptions by the Chinese consumers.

Furthermore, an empirical study by Jiang et al., (2023) examines how BT adoption for transparency in an online consumer marketplace affects consumer trust and revenue. Partnering with JD.com, a leading Chinese e-commerce platform, they found that consumers respond positively to BT-enabled product traceability, especially for products with sensitivity to handling or those sold by third-party sellers. The study quantifies a 23.4% increase in revenue for these BT-traced products, illustrating how BT enhances consumer trust by reducing information asymmetry. The findings suggest that transparency through BT is particularly beneficial for new sellers lacking established reputations, highlighting BT’s potential to reshape consumer marketplaces by improving consumer welfare and product reliability.

On the similar note, in a study on BT's impact on purchase intentions in food label protection, Acciarini et al., (2023) concluded that BT’s capability to secure and authenticate data positively influences consumer trust and purchase intentions. The study highlights how visible BT labelling on products can reassure consumers about product authenticity and safety, aligning with the increasing consumer demand for transparency, suggesting that BT not only supports product integrity but also encourages consumer loyalty, emphasizing the technology's potential as a strategic tool in the competitive food industry. While they effectively showcase BT's appeal in ensuring product integrity, BT requires a consumer base that understands and values of transparency. Whereas researchers such as Hakkarainen &

Colicev, (2023) explored how Blockchain-enabled advances (BEAs) such as smart contracts, cryptocurrencies, and non-fungible tokens (NFTs) are reshaping brand interactions and consumer behavior. This research provides a roadmap for brands to leverage BEAs for competitive differentiation, emphasizing the transformative potential of BT in customer engagement and brand equity. The authors propose a framework illustrating how BT's principles-decentralization, transparency, and immutability to empower consumers by enhancing control over personal data, fostering digital connectivity, and enabling secure transactions.

Moreover Bandinelli et al., (2023) investigated BT's potential to enhance transparency within the supply chain, specifically for ancient wheat pasta. Applying the Technology Acceptance Model in an Italian survey, findings reveal that BT's data immutability significantly boosts consumer trust by safeguarding information from fraud and manipulation. BT thus offers a robust solution for ensuring product credibility and satisfying consumer demand for transparent, high-quality food information.

Cao et al., (2023) proposed a BT-based traceability framework aimed at enhancing sustainability communication with customers within the food supply chain. They argue that BT's transparency and verifiability can address consumer concerns about food sustainability, offering a reliable alternative to traditional food labels, which may be prone to "greenwashing". The study also highlights BT's potential in sustainable supply chains, exploring regulatory support to ensure data integrity and industry standards.

Contini et al., (2023) investigated how BT can enhance consumer trust in credence attributes like organic and regional certifications, using a choice experiment centered on craft beer. Their results indicated that BT significantly strengthens consumers' trust in labels, which improves preference for products with verified credence attributes. In contrast, Shew et al., (2021) explored the preferences and WTP among U.S. consumers for BT-based traceability within the beef supply chain. Findings showed that consumers place greater importance on

USDA certification over BT traceability when purchasing beef. Although BT was recognized for enhancing transparency and traceability, it did not exceed the level of trust consumers associate with USDA certification. The study also highlighted a need for consumer education about BT's unique benefits in food traceability, as its association with cryptocurrency may cause misunderstandings. These findings suggest that to boost BT adoption in food traceability, it would be advantageous to couple educational initiatives with established certification systems, like USDA, to reinforce consumer trust and perceived value.

Rao et al. (2023) extend this investigation to China's tea industry, showing that consumers particularly young, educated, and high-income groups value BT traceability over traditional certifications, especially when exposed to knowledge interventions. This finding reinforces the importance of targeted awareness campaigns to facilitate BT acceptance among diverse demographics. Whereas in New Zealand, Wang and Scrimgeour (2023) explore factors affecting consumer adoption of BT food traceability, identifying two main segments: "Conservatives" and "Pioneers." The study shows that perceived complexity and consumer expertise play a significant role in adoption, illustrating that tailored strategies addressing segment-specific concerns could enhance BT uptake.

A study by Li et al., (2023) explored how BT alters the relationship between consumer trust and organic food adoption, finding that BT strengthens system trust in government certifications but weakens personal trust in individual producers. The study highlights BT's potential to reduce dependency on social trust, enhancing consumer confidence in organic labels. Whereas, researchers Wang & Scrimgeour, (2023) identified key factors influencing consumer adoption of BT food traceability, including perceived incentives and complexity. By segmenting consumers into "Conservatives" and "Pioneers," they reveal that motivations for BT adoption vary significantly by demographics and food preferences, with a preference for using BT for fresh, high-value foods.

Zhou et al., (2023) developed a game-theoretical model to analyze the effects of consumer skepticism on BT-enabled sustainability disclosure in supply chains. They suggests that while BT can reduce skepticism and promote WTP, high competition among manufacturers may lower overall profitability, benefiting retailers instead. In addition, factors like Government support might ease the cost burden on manufacturers, making sustainability disclosures more economically viable in the long term.

Whereas, researchers such as Zhang (2023) focuses on Swedish consumer attitudes towards BT traceability for olive oil. The study reveals a moderate level of BT awareness, with consumers prioritizing safety and sustainability verified by BT but placing greater importance on price and organic labels. This indicates that while Swedish consumers value transparency, BT ranks secondary to established attributes in their purchasing decisions.

Whereas, Ltifi & Mesfar, (2022) studied how BT's integration with CSR initiatives affects consumer behaviour within the airline industry, finding that CSR-driven BT transparency positively influences attitudes and resilience, ultimately leading to higher behavioural intentions and real behaviour. Moreover, a study by Dionysis et al., (2022) used the Theory of Planned Behavior to understand consumer purchase intentions for BT-traceable coffee. Their findings show that environmentally conscious consumers exhibit strong preferences for BT-backed transparency, aligning with an increasing demand for traceability However, it was seen on how BT traceability affects post-purchase behavior might enhance its integration in consumer goods, promoting a more resilient trust framework.

Mazzù et al., (2022) examined how BT can increase consumer trust in food supply chains by enhancing transparency and social responsibility. The study finds that BT's traceability benefits positively influence consumer attitudes, purchase intentions, and word-of-mouth intention by instilling trust in the information provided. However, while their findings highlight BT's potential for credibility enhancement, a broader focus on cross-industry applications could provide further insights.

Castellini et al., (2022) conducted a mini review to identify factors affecting consumer acceptance of BT in certifying sustainable food. The results showcased that while product-related technology features like traceability and transparency are widely recognized, individual and social factors, such as consumer risk perception and socio-demographic variables, are underexplored. This leaves scope for further studies on behavioural intervention strategies to enhance consumer acceptance of BT. Furthermore, education on BT's sustainability benefits could bridge the gap in consumer understanding, improving acceptance and driving more sustainable consumption behaviours. Moreover, in the U.S., Shew et al. (2020) examined consumer preferences for BT in food traceability, finding that USDA certifications are more influential in guiding consumer decisions than BT technology itself. This underscores the need for educating consumers on the value of transparency and data accuracy in product traceability rather than focusing solely on the BT technology. However, researchers such as Wang et al., (2021) employed a multimethod approach to study BT's impact on consumer behaviour across industries, showing that BT-enhanced transparency leads to increased sales and reduced product returns. By examining multiple cases, they identified that BT positively affects supply chain management, thus enhancing consumer trust and service quality.

Further examining adoption intentions, Yeh et al. (2019) use the UTAUT2 model in Taiwan to assess factors that influence consumers' BT adoption in food traceability. They find that trust, performance, and ease of use strongly shape consumer willingness, highlighting the trust-enhancing potential of BT's transparency for building purchasing confidence. Whereas, researchers Cao et al., (2021) explored a BT-based mechanism aimed at strengthening consumer trust in the beef supply chain between Australia and China. Through human-machine reconciliation, they proposed a model that allows for credentialed traceability and shared responsibility across stakeholders, from producers to consumers. They added that enhanced consumer awareness and understanding of BT-backed traceability could improve adoption rates and trust, especially in markets with frequent food fraud concerns. Similarly, Lin et al., (2021) assessed factors influencing Chinese consumers' intentions to adopt BT-based traceability for organic food, utilizing models like the Theory of Planned Behavior. Results show that attitudes and perceived behavioural control are significant drivers of adoption, while subjective norms play a lesser role with an additional focus on cross-cultural variances might provide further depth.

Boukis, (2020) explored BT's implications for brand-consumer relationships, particularly in terms of brand trust and transparency. The paper argues that BT can enhance brand credibility by enabling decentralized, tamper-proof records, reducing counterfeit risks, and fostering transparent communication to consumers. However, Boukis also notes potential challenges, such as privacy risks and reduced control for brands over customer interactions. Moreover, Knauer & Mann, (2020) explored drivers of BT acceptance among German consumers, finding that while BT is appreciated for its transparency and privacy benefits, adoption is limited by perceived complexity and unclear personal advantages. Concerns over security risks also dampen trust. The study suggests that for broader adoption, BT applications must focus on ease of use, trialability, and effectively communicating direct consumer benefits. Whereas, Sander et al., (2018) explored the acceptance of BT-based transparency systems within the meat industry, and their findings suggest that BT enhances consumer quality perceptions and purchase decisions by making traceability information more accessible and reliable.

2.3.6 Consumer Decision-Making, Information Processing, and BT Adoption

Blockchain Transparency and Consumer Information Processing

BT enhances supply chain transparency, allowing consumers to access real-time, immutable records of food traceability. However, the extent to which consumers engage with such information varies, influenced by factors such as perceived relevance, digital literacy, and information complexity (Vázquez Meléndez et al., 2024). Studies on food traceability adoption suggest that consumers value credible, verifiable information but do not necessarily engage with highly technical datasets. Instead, simplified, user-friendly formats, such as QR codes linking to concise summaries of key supply chain data, are preferred over detailed BT logs (Duong et al., 2024; Sepe, 2024).

Recent research indicates that consumer decision-making in digital environments is shaped by two primary mechanisms: heuristic processing (where consumers rely on trust cues, such as certifications or branding) and systematic processing (where they actively engage with and verify information) (Yang et al., 2024; Rao et al., 2023). The extent to which BT improves consumer trust depends on how accessible and interpretable the information is (Jiang et al., 2023). Studies in traceability systems for seafood and organic food markets show that while BT-backed data enhances perceived product authenticity, many consumers rely more on familiar certifications (e.g., USDA Organic, Fair Trade) rather than independently verifying blockchain records (Shew et al., 2021; Lin et al., 2021). This suggests that BT's role in consumer trust is complementary rather than standalone, requiring integration with recognizable quality assurance markers to drive widespread adoption.

Information Overload and BT Transparency

While BT enhances transparency, a critical challenge is information overload where excessive data availability overwhelms consumers, reducing engagement and trust (Hina & Islam, 2024). BT-based food traceability often provides granular details on sourcing, handling, certifications, and compliance records, but studies show that most consumers prefer summarized traceability reports rather than technical transaction logs (Vázquez Meléndez et al., 2024). Research on QR-code-enabled traceability demonstrates that when presented with overly detailed BT data, consumers either ignore the information or default to simplified heuristics, such as brand reputation or price signals (Rao et al., 2023).

Findings from digital transparency and food labeling studies suggest that to avoid information overload, BT-based traceability should prioritize clarity over complexity. For example, interactive digital labels that highlight key traceability attributes in simple, digestible formats (e.g., farm origin, sustainability claims, compliance certifications) improve consumer engagement without overwhelming them (Jiang et al., 2023; Sepe, 2024). Moreover, studies on food labelling in high-involvement product categories (e.g., organic food, premium seafood) show that while transparency increases trust, excessive or highly technical information discourages adoption (Acciarini et al., 2023). This indicates that BT's role in food traceability should focus on delivering essential, decision-relevant information rather than exhaustive data records (Yang et al., 2024).

Behavioral Barriers to BT Adoption

Several behavioral factors influence consumer engagement with BT-enabled food traceability. Perceived complexity is a significant barrier many consumers associate BT with cryptocurrency and financial transactions, leading to confusion about its role in food traceability (Shew et al., 2021). Studies show that BT adoption is higher among younger, tech-savvy consumers but remains low among older or less digitally literate consumers, who often default to traditional food safety labels rather than engaging with blockchain-verified traceability records (Li et al., 2023).

Additionally, status quo bias (a preference for familiar systems) affects blockchain adoption, as many consumers trust government certification schemes (e.g., USDA, EU Organic) over decentralized verification models (Knauer & Mann, 2020). Research on consumer skepticism in digital food labeling suggests that co-branding blockchain verification with recognized certifications enhances adoption, as consumers are more likely to trust hybrid models rather than fully decentralized verification systems (Zhou et al., 2023). Furthermore, trust in the entity managing blockchain data remains a key determinant of adoption while blockchain ensures data immutability, consumers care about who inputs the data, suggesting that independent third-party oversight is necessary to enhance trust (Contini et al., 2023).

2.4 Case studies

2.4.1 BT in the Agri-food sector

Several companies have been seen executing BT to bring innovation to enhance food safety and accomplish product provenance and transparent monitoring in the system through traceability to put checks on frauds (Hackett, 2017). For instance, BT has been deployed by 38 pasta, 37 beef, 37 milk, 35 coffee, 35 fish, and 1 beer companies to safeguard complete transparency throughout the supply chains (Antonucci et al., 2019). As described by Bumblauskas et al., (2020), a project by Bytable, the "Trace My Egg" project (https://tracemyegg.co.nz/) used BT (Hyperledger Sawtooth) for the digital traceability of each single egg pack where they used codes stamped directly onto eggs to help consumers identify eggs as free-range, barn-laid, caged, organic, or colony. Moreover, Walmart a retail giant has been working hand-in-hand with IBM since 2016 (https://www. hyperledger.org/resources/publications/walmart-case-study), on their pilot study of food traceability in the BT (Hackett, 2017). In 2018, Walmart initiated their suppliers to get involved in the BT (IBM, 2017). Soon after Walmart, big names in the industry like, Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, and Unilever started to invest and collaborate with IBM to test and implement the BT in their SC operations (IBM, 2017). Similarly, Alibaba collaborated to create a BT-based platform with Blackmores, an Australian health supplements company, and other Australian and New Zealand-based manufacturers and suppliers to challenge the increase in counterfeiters targeted on food items sold in China on their platform (Motta et al., 2020; Rejeb et al., 2020).

Moreover, Maersk in September 2016 did a Proof of Concept (POC) with IBM, to track a container of flowers from Kenya to Rotterdam (Kamath, 2018). Also, succeeding to this, they conducted a few pilots, including the international shipment of electronics from Rotterdam to Newark, and the shipment of Mandarin oranges from California and pineapples from Colombia to Rotterdam, whereas both pilot projects were completed in 2017 (Kamath, 2018). Their objectives in these projects were to implement BT and digitalise the international trade to go paperless completely while providing an end-to-end visibility to encourage transparency (IBM,2017b). Global brands Unilever and Sainsbury's have together started working with leading investors to pilot that how BT technology can financially reward sustainable farming practices for Malawian tea makers (The Grocer, 2020). Another one of the lead tech startups in BT called Bext360, launched a pilot project in Ethiopia to give all stakeholders access to data throughout the entire supply chain of Moyee Coffee (www.moyeecoffee.ie) with FairChain Foundation in November 2017. Bext360 platform used a technique to instantly generate crypto tokens which, automatically generated new tokens with their value increased at each node, as the goods flow through the entire supply chain. This successful attempt between these two companies was to create a fairer and more honest supply chain (Moyee Coffee, 2018). Moreover, AgriDigital, employed the world's first grain sale of 23.46 tons on BT involving $360 million in grower payments (ICT4AG,2017). The massive success of AgriDigital is inspirational to implement and execute BT in the agri-supply chain (AgriDigital, 2017). As another example, one of the leading giants in the foodstuff trading industry, Louis Dreyfus Co (LDC), collaborated with the Dutch and French banks for cargo of soybeans from the US to China, on BT (Kamilaris et al., 2019; Tripoli & Schmidhuber, 2018). During this successful implementation, LDC claimed to reduce document processing by a fifth of the time, due to the improved auto-matching real-time data to avoid duplications caused during manual checks.

2.4.2 BT in the fisheries and aquaculture sector

The Fisheries and aquaculture sector is one of the most vulnerable sectors noted for food fraud and lack of an efficient traceable system which lacks end-to-end transparency. Thus, considering the need of the hour to address the issues in the sector, several studies were identified focusing on BT adoption in fisheries and aquaculture supply chains, such as Cook, (2018) explored the BT adoption in the fisheries and aquaculture supply chain (FASC) and investigated the benefits and challenges of a BT application through a pilot project focusing on combating illegal tuna caught in a Fijian longline, led by the Worldwide Fund for Nature (WWF). The results stated that BT could bring end-to-end transparency to the system, building a trustworthy FASC due to the transparency offered, which addresses fraud identification in real time (Cook, 2018). WWF also partnered with Viant and Sea Quest Fiji Ltd. on a project to create a transparent BT traceable tuna supply chain in which every part of the fish was marked and verified at the arrival stage and brought to processing, whereas, during processing, the tag remained with the fish through the entire process to ensure the continuity of the fish's history. This tag will be removed in the packaging process and replaced with a unique QR code that matches the fish when it is sent to the market. Similarly, Fishcoin, a BT-based data ecosystem dedicated to the seafood industry, uses tokens to incentivize stakeholders for data capture and transmission across fish supply chains to increase traceability (Fishcoin, 2018). Additionally, a UK social enterprise organisation called Provenance has been considered one of the pioneers in providing tracking and tracing solutions for the fisheries supply chain. They have effectively brought two pilot projects to success which are: a) to track tuna supply chains through Southeast Asian in 2016; b) to track fresh produce from its origin to the supermarket in 2017 with a large cooperative business. They mainly focused on increasing the integrity of certifications, along with safeguarding food traceability and fair payment activities (Provenance, 2016).

2.5 Conclusions and future research

Several considerations can be derived based on the outcomes that emerged from this review: First, the findings suggest that BT has gained significant traction in academic research over the past seven years, owing to its potential to tackle critical challenges related to traceability, transparency, and sustainability in the agriculture and food supply chain (AFSC). Various studies support this such as Adamashvili et al., (2021); Park & Li, (2021); Sander et al., (2018); and Tayal et al., (2021).

Second, it was found that China, India, and Italy are the top three countries actively researching BT studies in AFSC/FASC. This finding can be confirmed by researchers such as Peng et al., (2023); Rejeb et al., (2021); and Wamba & Queiroz, (2020).

Third, we identified various benefits and costs of BT adoption in the agri-food sector from the literature and grouped them based on their categories, such as supply chain benefits, market benefits, risk and recall benefits, food safety and quality benefits, and regulatory benefits, as well as costs such as implementation and operations costs. The decentralized and distributed nature of BT offers immutability of data and shares credibility of information among stakeholders and consumers, thus enhancing trust throughout the supply chain (Akella et al., 2023; Bandinelli et al., 2023). This allows for better coordination, visibility, and traceability, as well as easy detection of food frauds, which, in turn, builds consumers' confidence in brand building, as supported by other studies (Callinan et al., 2022; Olsen et al., 2022). However, the reviewed literature shows that most studies focused on either literature reviews of BT implementation in AFSC or theoretical frameworks/models for its implementation (Dey & Shekhawat, 2021; Luna et al., 2023; Patro et al., 2022; Pournader et al., 2020; Rampone et al., 2023; Xu et al., 2019). There is a significant gap in empirical research on the practical adoption of BT in AFSC.

Fourth, several articles have highlighted the suitability of BT in both AFSC and FASC due to its decentralized and immutable features of real-time data sharing among stakeholders (Patro et al., 2022; Yin et al., 2022). This can help enhance high production standards, restrict contamination, and provide wide visibility throughout the supply chain (Cao et al., 2022; Prashar et al., 2020). Other studies have corroborated the benefits of BT for food safety concerns, such as the early detection of banned chemicals, contaminations or residues of antibiotics (Aya et al., 2021; Ortega et al., 2014, 2015), and the check on fraudulent activities (Cook, 2018; Dos Santos et al., 2021; Helyar et al., 2014; Howson, 2020).

Lastly, it shows that in the FASC sector, shrimp is the world's top traded and consumed seafood product, accounting for approximately 15% of global seafood (FAO, 2022) and is associated with the most seafood fraud reports globally (Lawrence et al., 2022). Despite such importance in global trade shrimp supply chains are hardly explored in terms of the existing challenges and the use of technology adoption to solve them. India is one of the top exporters of shrimp globally. Still, there is a notable gap in empirical evidence of BT adoption in the Indian shrimp supply chain (ISSC) on its ongoing challenges and their prospective solutions using emerging technologies such as BT Holger et al., (2020); Juditstarlin & Jothi, (2021); Salunke et al., (2020).

To conclude, considering the outcomes of the review, there is a vast potential success for BT adoption in the agri-food or allied sector. However, due to the primary stage of practical implementation, a considerable number of case studies, especially on the adoption of BT in FASC, lack success. Thus, further studies can be recommended considering the sparse literature on the topic and to fill the void of the empirical research studies on BT adoption in AFSC/FASC. Firstly, these outcomes strongly recommend an exploratory survey of stakeholders' perceptions and thoughts on the benefits and costs of BT adoption in AFSC/FASC. Second, the sparse literature on the consumer side of BT adoption suggests a consumer valuation study, such as choice experiments, which would highlight the consumer demands for BT adoption in the supply chain. The outcomes of these studies would offer suggestions and directions for the future of BT acceptance in the Agri-food and allied sectors.

CHAPTER 3: Fisheries, and aquaculture sector: An Overview

This chapter provides background information about the fishery and aquaculture sector (FAS) both globally and, more specifically to India. The chapter is divided into five sections. The first section provides an overview of the FAS, the second section discusses the current global trends in FAS, followed by the third section on the current trends in Indian FAS. Next, the fourth section discusses major challenges in the sector, followed by the fifth section which describes the shrimp production scenarios and trends both globally and in India.

3.1 Introduction

Seafood is an essential source of substantial nutrition in the human diet in many areas across the world, where all fish products are identified not only as some of the healthiest foods on the planet due to their rich protein source but also as one of the least impactful on the natural environment (Gopi et al., 2019; Symes & Phillipson, 2019). For these reasons, seafood products are vital for national, regional, and global food security, and nutrition strategies, to play a key role in transforming food systems and reducing hunger and malnutrition (FAO, 2020). Thus, fish is one of the most traded food products and has been recognised to play a crucial role in food security and nutrition (FAO, 2022). However, with the increase in international trade and the rising demand for seafood, the role of developing economies like India, Thailand, Ecuador, Argentina, Bangladesh, and Vietnam are noted to be significant to the ever-increasing demand for seafood. These countries have shown a faster growth rate of exports in last 40 years, than several developed economies (FAO Fisheries and Aquaculture Proceedings, 2018). Some of the major reasons for this boost could be the soaring demand as a result of increasing income, urbanisation, the advancements in post-harvest methods in fish production, and a faster supply chain that helps commercialisation of fish (Tran et al., 2017). Additionally, changes in dietary trends with more focus on better health and nutrition fish plays a crucial role in new diets (Khan, 2018). However, there is a consistent decline in marine fisheries stock or at total capacity within sustainable fishing levels with 59.6 % grouped as being maximally sustainably fished stocks and 6.2 % underfished stocks (FAO, 2020), thus aquaculture[2] is anticipated to fulfil the remaining demand-supply gap (Bush et al., 2019).

3.2 Trends in global fishery and aquaculture production

Globally, fishery and aquaculture products provide about 3.3 billion people with almost 20% of their average per capita intake of animal protein (FAO, 2022). About 88 % (156 million tonnes) of the fish produced worldwide was used for direct human consumption, while the remaining 12 % was used for non-food purposes, of which fishmeal and fish oil covers 88 % (FAO, 2022). Considering the direct consumption of fish, chilled or fresh/live fish still shares a larger portion (44 %), followed by frozen fish (35 %), prepared and preserved fish (11 %), and cured at 10 % (FAO, 2022). The seafood market shows a range of diversified products that represents the variety in consumer preferences and tastes. Among all species, salmonoids[3] were the most traded species (19%) of total value in the global market, followed by other species with high demand such as shrimps and prawns (15%), followed by groundfish such as haddock, cod, Alaska pollock, etc. (10%), and tuna (9%) (FAO, 2022).

As per the latest report from the Food and Agriculture Organisation, total fisheries and aquaculture production is seen to reach 214 million tonnes in 2020, which is an all-time high, comprising 178 million tonnes of aquatic animals and 36 million tonnes of algae, a slight increase (3 %) from the previous year-on-year record (213 million tonnes)(FAO, 2022). It was noteworthy that global fish captures were severely disturbed by the interruption to fishing operations caused by the COVID-19 pandemic with a cut by 1.6 % in 2020 (FAO, 2022). However, among the top ten global fish producers, especially nations like Peru, India,

[2] Aquaculture-It is the practice of farming seafood. It is similar to agriculture, but done with fish, crustaceans and shellfish (ASC International, cited on 15/09/2021).
[3] Salmonoid- Salmonidae is a family of ray-finned fish which includes salmon, trout, chars, freshwater whitefishes, graylings etc., which are collectively known as the salmonids.

the Russian Federation, and Norway, reported that catches in 2020 were either at the same level or higher than the catches for 2019 (FAO, 2022). Moreover, it was seen that out of total world fish production, 89 % (157 million tonnes) (excluding algae) was utilized as direct human consumption, as compared with 67 % in the 1960s (FAO, 2022). Whereas the remaining (over 20 million tonnes) was utilized for non-food purposes such as majorly for fishmeal and fish oil, and the rest for ornamental fish, bait, pharmaceutical applications, pet food, and direct feeding in aquaculture and raising of livestock (FAO, 2022).

3.2.1 Capture fisheries

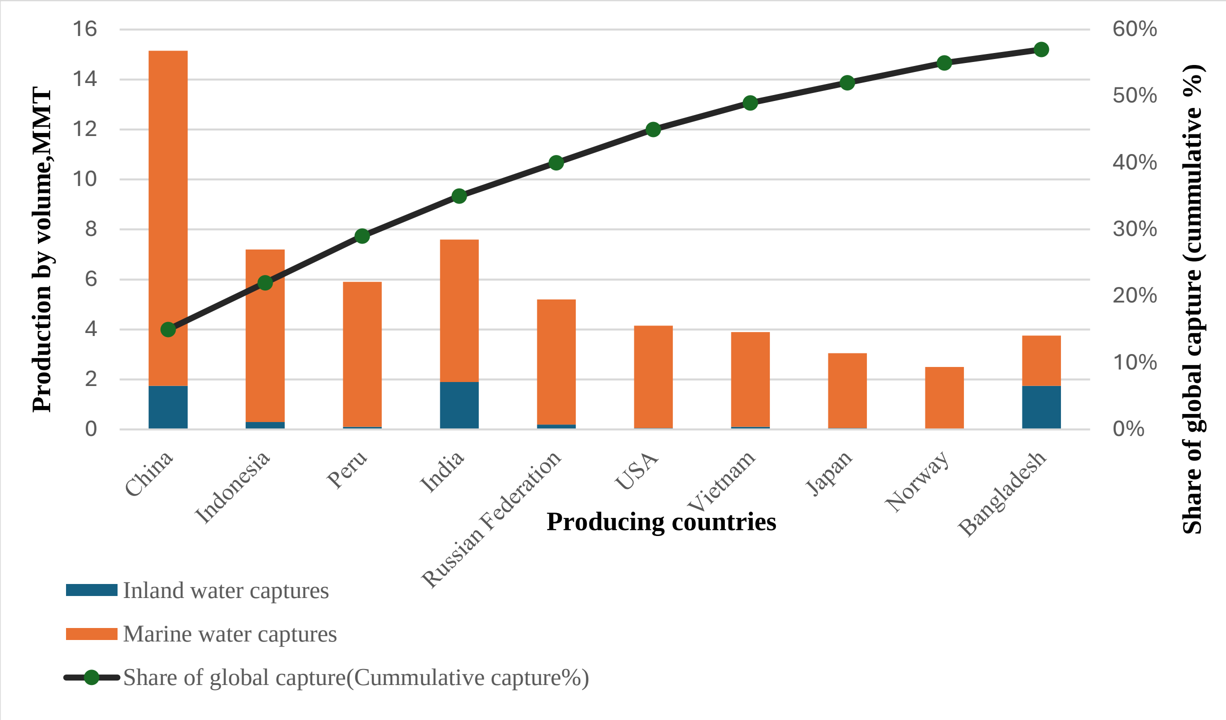
Marine capture

The global capture fisheries production (excluding algae) in 2020 was noted at 90.3 million tonnes, with an estimated value of USD 141 billion, including 78.8 million tonnes from marine waters and 11.5 million tonnes from inland waters (FAO, 2022). Whereas, among these catches the four most high-value groups (tunas, cephalopods, shrimps, and lobsters) remained at their highest levels. In 2020 regardless of a decline of 5.1 % from 2019 due to Covid-19, the global catches in inland water achieved historical production estimated at 11.5 million tonnes (FAO, 2022). However, it was seen that Asia produced almost two-thirds of total inland fisheries with the top four out of five producers being Asian countries where China topped the chart with 85,948 MMT tonnes of total production, followed by Indonesia (21,813 MMT), and India (14,433 MMT), Vietnam (8,289 MMT) and Peru (6,726 MMT) (Globefish, 2023).

The growth in 2020 was majorly driven by marine capture fisheries, whose production increased from 81.2 million tonnes in 2019 to 84.4 million tonnes in 2020, including the catches from inland fisheries[4] also recorded their highest-ever catches, at over 12 million

[4] **Inland fisheries**- Inland fisheries are any activity performed to extract fish and other aquatic organisms from inland waters, like lakes, rivers, brooks, streams, ponds, inland canals, dams, and other land-locked

tonnes (FAO, 2022). China remained the top marine fishery producer –despite the fall in its catches for the years 2015–2020 (FAO, 2022). In 2020, the top 7 producers were responsible for over 50 % of the total marine captures, of which China accounted for 15 % of the world total (Figure-4), followed by Indonesia (6.9 %), Peru (5.8 %), India (5.7 %), the Russian Federation (5 %), the United States of America (4.1 %), and Vietnam (3.8 %), whereas the top 20 producers accounted for almost 73 % of total global capture production (FAO, 2022).



(Source: FAO, 2022)

Figure 4- Top 10 global marine and in-land fishery products

<u>Inland captures</u>

Global inland captured fisheries too were severely affected by the Covid-19 pandemic during 2020 combined with reduced catches in China for a longer period, and thus showed a decrease of production by 5.1% with 11.5 million tonnes of volume production with impressively just a marginal lower level of 12 million in 2019. India was the top producer

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(usually freshwater) water bodies (FAO https://www.fao.org/inland-fisheries/en/#:~:text=Inland%20fisheries%20are%20%22any%20activity,source%20of%20food%20for%20mankind, Cited on 11/01/2023).

of inland capture fisheries with 1.8 million tonnes of production followed by China with 1.5 million tonnes, Bangladesh (1.3 million tonnes), Myanmar (0.8 million tonnes), and Uganda (0.6 million tonnes) respectively (FAO, 2022).

3.2.2 Aquaculture

Aquaculture has shown a dominance in global fish markets showing substantial implications for fish distribution and consumption (Koehring, 2021). Due to the better control over the production processes as compared to wild fisheries, fish farming is more encouraging for vertical and horizontal integration in fish production and value chains (Parreño-Marchante et al., 2014). Subsequently, aquaculture has made it easier for local production and exports of species especially such as shrimps, salmon, tilapia, carp, and catfish in countries which otherwise had scarce or no access to such cultures species and at lower prices helping in countries better nutrition and food security (Kimani et al., 2020).

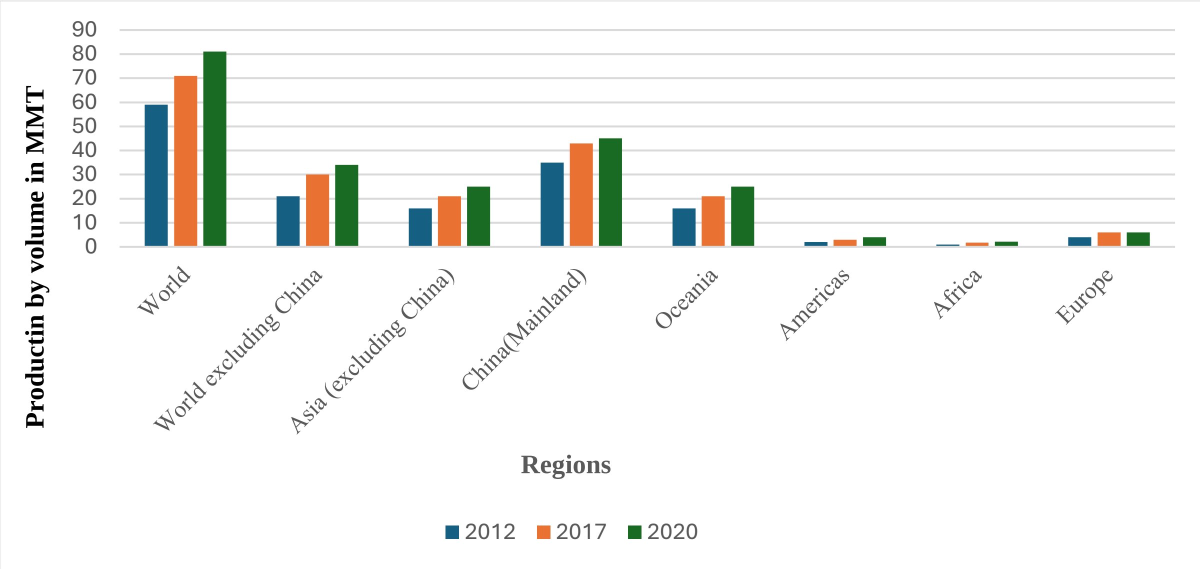
Asia leads the world aquaculture market among all the continents in the production of farmed aquatic animals, with an 89 % share with the leading producers as China, India, Indonesia, Vietnam, Bangladesh, Egypt, Norway, and Chile, who strengthened their share in regional and world production exponentially over the past two decades (Statista, 2022b). The contribution of world aquaculture to the fish production and international trade in 2020 grew by 2.7% compared to 2019, with 87.5 million tonnes of aquatic animals (human food), 35.1 million tonnes of algae (food and non-food uses), 700 tonnes of shells and pearls for ornamental use, reaching a total of 122.6 million tonnes in live weight (FAO, 2022).

As per a report from Food and Agriculture Organisation, farmed finfish was top in the chart in production at 57.5 million tonnes (USD 146.1 billion), followed by other farmed aquatic animal species such as molluscs[5] such as bivalves with 17.7 million tonnes (USD 29.8

[5] Molluscs- is the group of animals that includes creatures such as gastropods (snails, slugs, limpets etc), bivalves (clams, oysters, mussels etc), cephalopods (octopuses, nautiluses, squids etc), scaphopods (tusk shells) (Natural history museum, University of Oxford- Cited on 10/03/2023).

billion), 11.2 million tonnes of crustaceans such as shrimps (USD 81.5 billion), 0.52 million tonnes of aquatic invertebrates (USD 2.5 billion) and 0.53 million tonnes of semi-aquatic species such as turtles and frogs (USD 5 billion) (FAO, 2022).

World aquaculture production of farmed aquatic animals has shown an annual growth increase with substantial figures from China being a leader, followed by Asia (excluding China), Oceania, and other regions as shown in Figure 5.



(Source: FAO, 2022)

Figure 5-Aquaculture fish production growth in the last decade (2012-22)

Inland aquaculture

Inland aquaculture is also called freshwater aquaculture as the farmed aquatic animals are mainly produced in freshwater. This type consists of farms such as the use of earthen ponds, tanks, aboveground tanks, pens, and cages according to the region and condition. Whereas, in Asian traditional farms, a rice-fish culture is used, where fishponds are commonly built with rice farms. (Bush et al., 2019; Katiha et al., 2005).

As per FAO, the inland aquaculture produced 49.3 million tonnes of fish and other aquatic animals in volume at the USD 36.2 billion market value, which was the world's 62.5 % of the farmed fish production. Moreover, a strong growth rate of production of other species especially crustacean such as shrimps, crayfish and crabs outnumbered the finfish. Inland aquaculture includes high production of white-leg shrimp in freshwater in Asia and some parts of China (FAO, 2022).

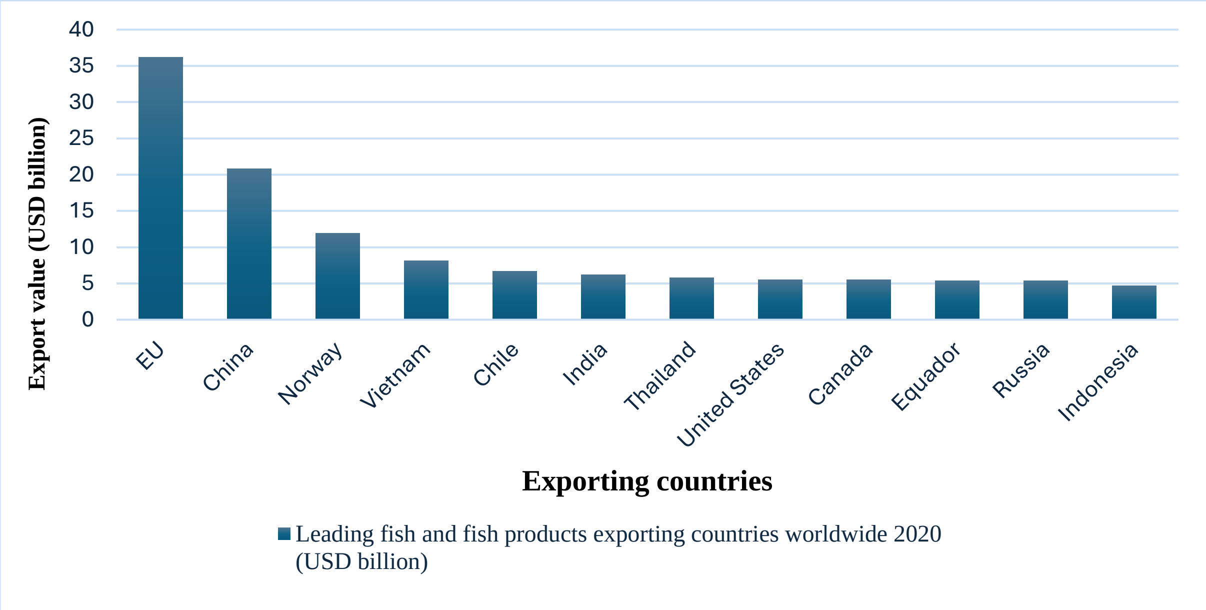
Mariculture (Marine aquaculture) and coastal aquaculture

Mariculture aquaculture practice is followed in the sea or marine environment. For the species whose seeds are produced in hatcheries and nursery setups, mariculture represents a grow-out phase of the production cycle. As per a report, both mariculture and coastal aquaculture together produced 8.3 million tonnes (USD 36.2 billion) of aquatic animals in 2020. The share of molluscs was the highest accounting for 54.6 % of total production alone followed by Finfish, and crustaceans holding 42.5 % of the share together (FAO, 2022).

3.3 Global export and import

3.3.1 Exporters

The European Union (EU) was the largest exporter of fish and fish products worldwide in 2020 (USD 36.2 billion) in export value, followed by China (USD 20.8 billion), Norway (USD 11.9 billion), Vietnam (USD 8.1 billion), Chile (USD 6.7 billion), India (USD 6.2 billion) and other following as shown in figure-6 (Statista, 2022b).

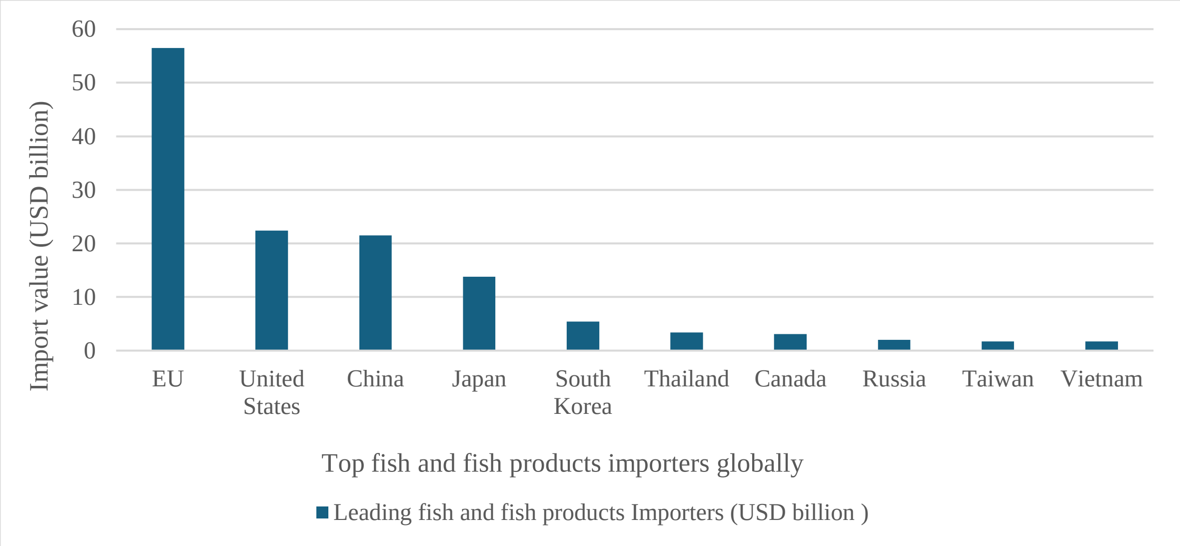


(Source: Statista, 2022)

Figure 6-Leading fish and fish products exporting countries worldwide

3.3.2 Importers

In terms of regions, the EU stands as the biggest market to import fish and fish products with a 34% market share at USD 56.5 billion, followed by the USA with USD 22.4 billion, China (USD 14.9 billion), Japan (USD 13.2 billion), Spain (USD 7.1 billion), and France (USD 6.2 billion) respectively (Figure 7) (Statista, 2020).



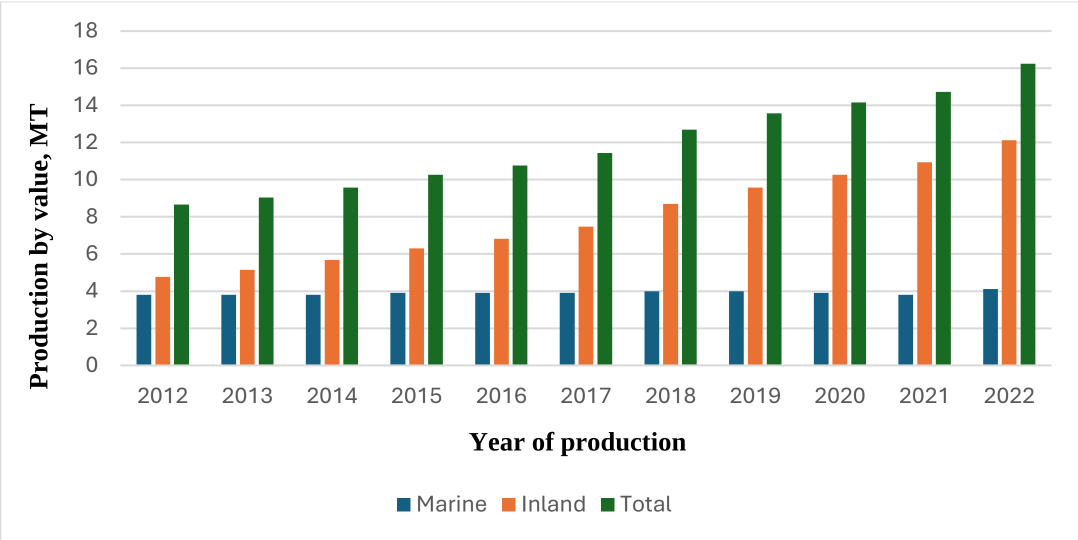
(Source: Statista, 2022)

Figure 7-Leading fish and fish products importing countries worldwide

3.4 Trends in Indian marine fishery and aquaculture production

3.4.1 Production

Globally, India is the third largest fisheries and aquaculture fish producer only after China, and Indonesia globally with 16% of total inland, and 5% of global marine fish production respectively (DoFGI, 2022). Fisheries and Aquaculture sector (FAS) contributes approx. 1.1% to the Indian economy, and about 6.72% to the agriculture sector (DoFGI, 2022). Thus plays a vital role in overall socio-economic growth enabling as a high income and employment generator in India that stimulates growth of several subsidiary industries being a source of cheap and nutritious food besides being a foreign exchange earner (BCG, 2020). According to the government report by NFDB, (2022) fish capture and production has shown steady growth in Indian FAS in the last decade rising from nearly 8.67 million metric tons (MMT) in 2012 to 16.24 MMT in 2022 of fish capture (marine & In-land) with contribution of 12.12 MMT from in-land and, 4.12 MMT from marine sector (figure-8) while 86.5 MMT were bred, raised, and farmed (aquaculture) through the controlled aquaculture process (NFDB, 2022). Whereas the marine export of India stood at 1.55 MMT valued at USD 52.6 million, and the USA remains a top importer of Indian seafood with an import value of USD 24047.15 million.



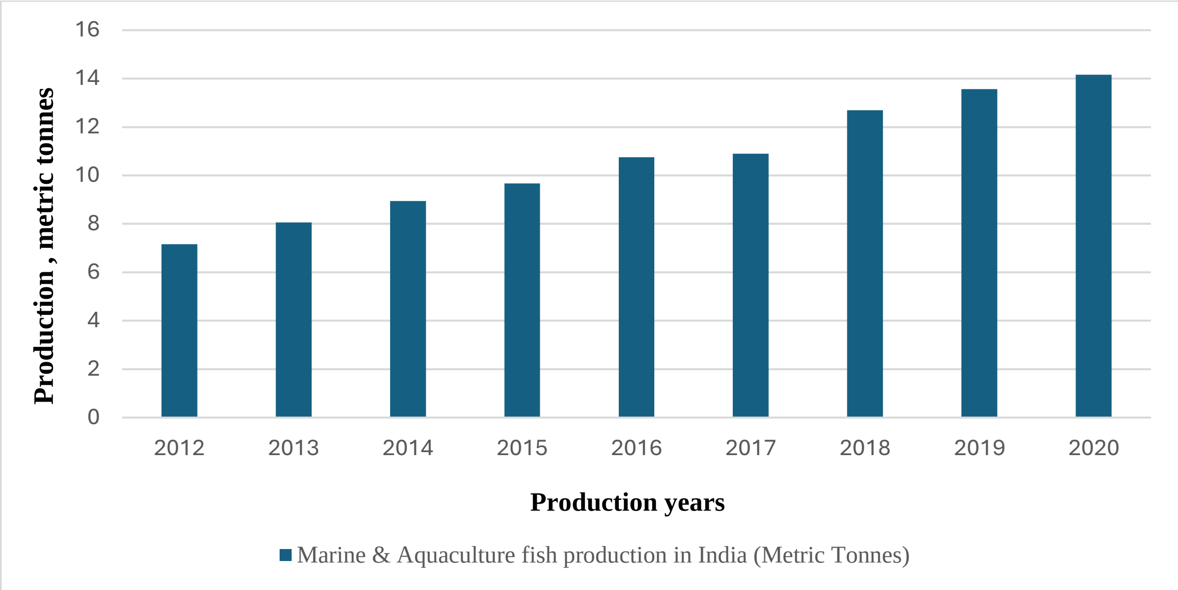
(Source:NFDB, 2022)

Figure 8-Fish production growth of India in the last decade(MMT)

In India approx. 14.5 million people are engaged in fisheries (both marine and aquaculture) and its allied activities, and about 17 % of agriculture exports of the country are fish and fish products (DoFGI, 2022). Whereas among the states, Andhra Pradesh is the country's highest fish producer followed by West Bengal and Gujarat respectively (DoFGI, 2022).

India is an exporter of more than 50 different types of fish and shellfish products to 75 countries around the world (FAO, 2022). Marine and aquaculture fish, and fish products have emerged as the largest group in agricultural exports from India, with 13.77 MMT in terms of quantity (volume) (Figure 9) and $USD 7.08 billion in value (Figure 7). This accounts for around 10% of the total exports and approx. 20% of the agricultural exports and contribute to about 0.91% of India's gross domestic product (GDP) and 5.23% to the Agricultural Gross Value Added (GVA) of the country (NFDB, 2022).

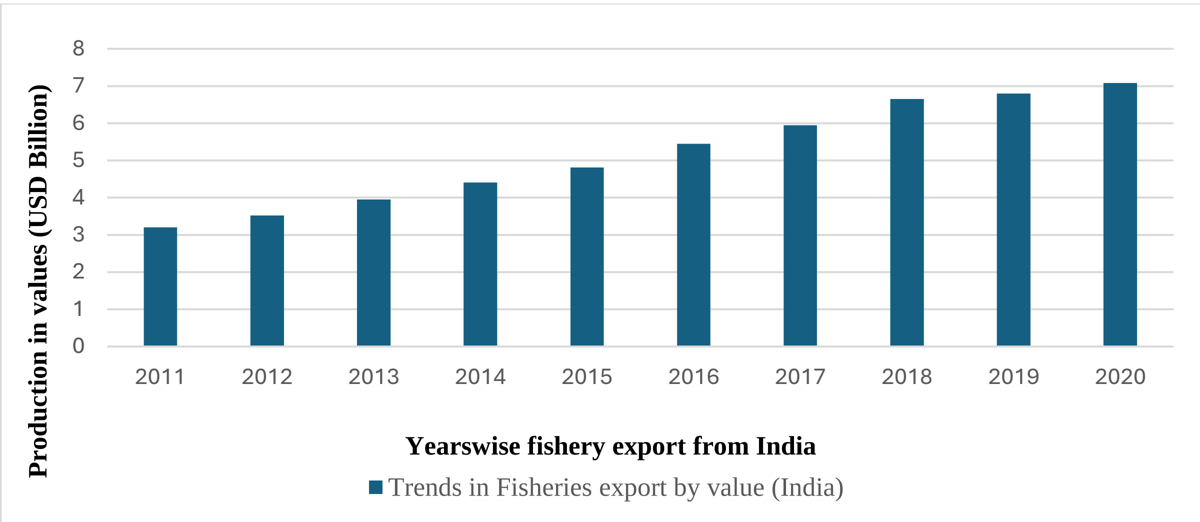
Gradual growth is seen in the rise in fishery production in India from 2011-12 to 2021-22 as per the rising demand for the fish and fish products worldwide (Figure 9). The highest-traded seafood product in exports from India is shrimp.



(Source:DoFGI, 2022)

Figure 9-Marine & Aquaculture fish production in India

India has shown steady growth in exports of Marine and Aquaculture fish in the last decade, with an all-time high of USD 7 billion in recent trades (Figure 10), which shows a high potential growth for Indian fish globally.



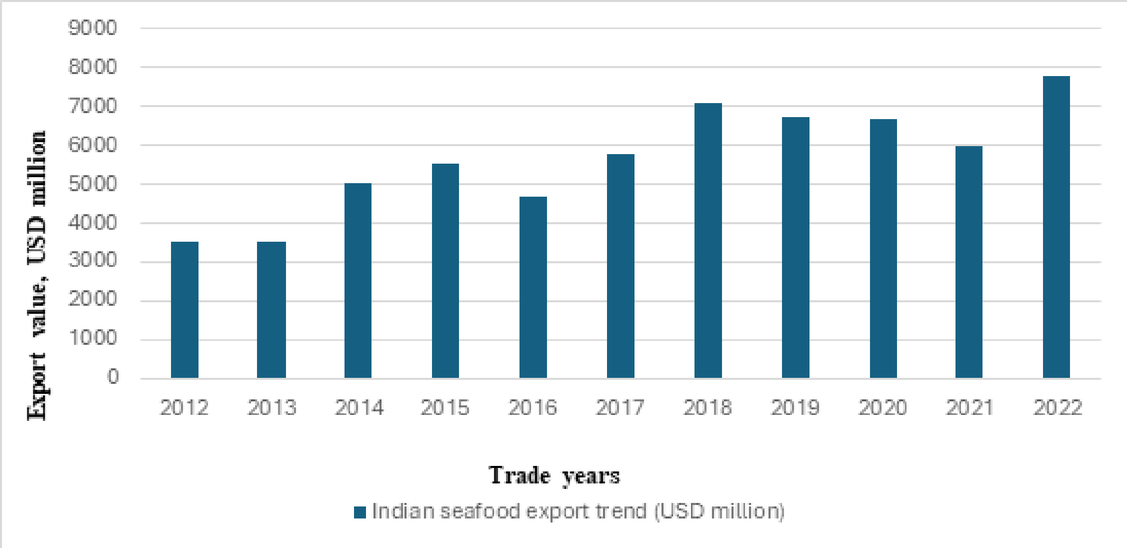
(Source:NFDB, 2022)

Figure 10-Trends in Fisheries export by value (India)

3.4.2 Indian seafood export trend

Indian fish and fish product export showed an exponential growth of 19.12 % in quantity and 31.71% in terms of value in FY2021-22 with 1,369,264 MT volume of export of value USD 7759.58 million as compared to 1,149,510 MT at USD 5956.93 million in 2021 in FY 2020-21 year-on-year (DoFGI, 2022). Moreover, despite all odds in the supply chain and reduced demand from top importers in the world, FY 2022-23 noted a considerable rise of 26% in the export of 1,735,286 MT of Indian seafood with a value USD 8.09 billion, compared to 13,69,264 MT (USD 7,759.58 million) in 2021-22. Frozen shrimp continued as the top export product where the USA and China are the top importers of Indian seafood products (MPEDA, 2023). The top export product frozen shrimp fetched USD 5481.6 million accounting for 40.98% in quantity and 67.72% share of USD value. Whereas, the second top export product frozen fish stood at 62.65% growth in quantity and 45.73% growth in value with USD 687.05 million respectively (MPEDA, 2023). Similarly, 'Other items' category products exports were valued at USD 658.84 million which included products such as frozen octopus (USD 91.74 million), canned products (USD 41.56 million), frozen lobster (USD 27 million), etc. Frozen squid the fourth top exported product stood at USD 445.61 million, and dried items noted an export of 2,52, 928 MT with 243.27% growth in quantity. EU continued to be the third largest destination for Indian seafood with 2,07,976 MT worth USD 1,263.71 million. South East Asia is the fourth largest market with an import of 4,31,774 MT worth USD 1191.25 million followed by Japan with 6.29% in quantity and 5.99% in USD value (MPEDA, 2023). Overall, high growth of the Indian seafood export trend is noted in terms of value (USD million) in the last decade 2012-2022.

Consistently in the last decade frozen shrimp is the top revenue generator for Indian seafood export with the volume of 728,123 MT and valued at USD 5828.59 million in FY2021-22, followed by frozen fish (226,586 MT, USD 471.45 million), frozen cuttlefish (58,992 MT, USD 280.08 million), frozen squids (75,750 MT, USD 383.37 million), live fish (7,032 MT, USD 47.98 million), dried fish (73,679 MT, USD 143.46 million), and other products (177,414 MT, USD 540.73 million) are in high demand locally and globally with a steady growth as shown in Figure 11. Following are the trends of the Indian fish products in terms of exports, where shrimp being top of the list.



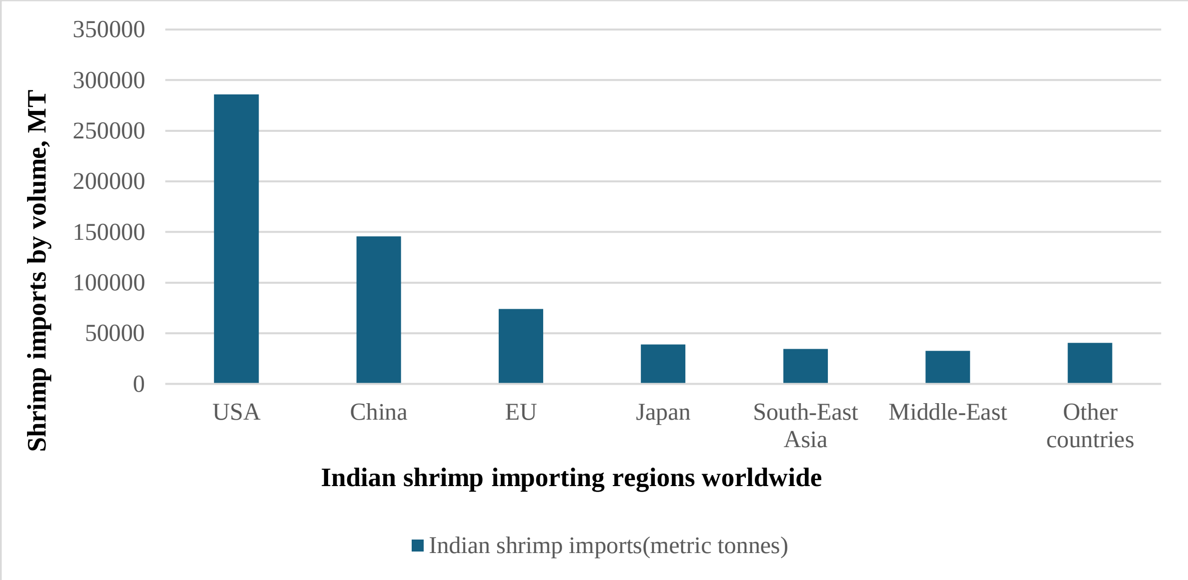
(Source: DoFGI, 2022)

Figure 11-Share of Indian fish product export

3.4.3 Top export seafood product of India-Frozen Shrimp

Frozen shrimp was noted as the highest exported product in terms of quantity and value adding for a share of 54.34 % in quantity and 72.11% of the total USD earnings. Shrimp exports during 2020-21 have increased by 6.04% in USD value and 6.20% in quantity. The overall export of shrimp by volume during 2020-21 was to the set of 728,123 MT[6] (Figure 12) worth USD 5828.59 million. USA was the largest market imported (285,904 MT) of frozen shrimp followed by China (145,710 MT), the European Union (74,035 MT), Japan (38,961 MT), Southeast Asia (34,439 MT), the Middle East (32,645MT) and Other Countries (40,560 MT) (DoFGI, 2022).

[6] MT-Metric Tonnes-metric unit of mass equal to 1,000 kilograms



(Source:DoFGI, 2022)

Figure 11-Indian shrimp importing countries

3.5 Major challenges in the seafood sector

Regardless of the numerous food safety regulations being put in place, the cases of food fraud, violations of human rights, and environmental deprivation are seen in general in the food sector, especially in the seafood industry. Moreover, identifying and reporting these frauds is the next challenging task due to less or no monitoring (Bénard-Capelle et al., 2015; Cawthorn et al., 2015; FAO, 2020).Efficient monitoring to safeguard the environment and prevent the exploitation of natural habitats in FAS is lacking. This has resulted in various challenges in the sector, such as overfishing, IUU fishing, and disease issues. Several challenges in current FAS have been identified and described below.

3.5.1 Lack of traceability

Traceability is defined as the process of tracing a product from the sale point back to its origin. Considering the seafood sector, this is the ability to get all the information about the fish caught throughout the supply chain such as where the fish was caught, who caught the fish, the type of gears used, etc.(Jose & Prasannavenkatesan, 2023; Kochanska, 2020). Most fishers/farmers lack information about market prices, and the downstream actors gain increasingly higher ratios of the product value for higher-value species as middlemen adversely control market benefits that should accrue to primary producers (Bailey et al., 2016). Thus, improved traceability induces transparency of prices to fishers/farmers which could empower them to negotiate higher prices, especially for more valuable species (Gagalyuk et al., 2010).

3.5.2 Lack of transparency

Transparency in fish value chains largely concerns the disclosure of information in the supply chain among actors in various segments (e.g., production practices, sourcing materials, and prices) (Blohmke, 2019). The seafood industry suffers from unsustainable resource management, inefficiencies in operations, and distrust across stakeholders in the supply chain. improve operating efficiency across the supply chain, but also ensure that the end consumers have access to trustworthy product information. There is little accountability across the supply chain among stakeholders due to a lack of traceability(Bazzani et al., 2017; X. Lin et al., 2021a). Therefore due to non-transparent supply chains, traders and processors often possess market information exclusively and every so often create exploitative social relations with fishers/farmers (Nielsen et al., 2017). Thus, improved transparency could be one mechanism to improve the sustainability in global supply chains generally where producers empowered with market information could make better decisions for production and trade (e.g. timing of harvests, negotiating prices) (Mondragon et al., 2020; Kefi et al., 2017).

3.5.3 Lack of information of origin

The businesses that trade seafood, with the lack of product origin information and supply chain transparency, could pose significant risks (Mai, Bogason, Arason, Ehf, et al., 2010; Tharun et al., 2018). Seafood supply chains are complex in nature with numerous stakeholders such as growers, farmers, processors, exporters, etc., and are physically dispersed, which leads to a lack of true information on the origin of the product leaving scope for fraudsters to claim false information to gain premium profits (Mulyono et al., 2019; Wang et al., 2022).

3.5.4 Food loss in the Fishery value chain

Globally in the fisheries sector, it is most likely that 35 % of the global harvest is either lost or wasted every year (Kruijssen et al., 2020). In most parts of the world, total physical loss and waste lie between 30 % and 35 %. North America and Oceania are found to be highest where half of the caught fish is wasted at the consumption stage, whereas in Africa and Latin America, losses occurred due to lack of preservation infrastructures and knowledge or due to inefficient value chain (Kumolu-Johnson and Ndimele, 2011). Thus, with the use of efficient systems and effective supply chain operations, the loss of seafood can be mitigated.

3.5.5 Frauds in marine and aquaculture fisheries

The complex and often extremely opaque nature of FASC, a high occurrence of fraud is observed throughout the supply chain (Lawrence et al., 2022). Fish food fraud is the practice of misinforming consumers about their seafood for financial gain (Meloni et al., 2015). Such fraud includes criminal activity such as mislabeling, substitution, counterfeiting, misbranding, dilution, and adulteration. Food crime involves any criminal conduct that affects the safety or authenticity of food (Reilly, 2018).

A study by Fox et al., (2018) on AFSC, has elaborated different AFSC frauds as “nine sins of seafood” which include three separate categories; adulteration including species substitution, adulteration, and undeclared product extension; provenance comprising fishery substitution and chain of custody abuse and ethical trade consisting of illegal, unregulated and under-reported substitution, catch method fraud and animal welfare (Fox et al., 2018).

Every single node in the FASC poses an opportunity for one or more of the nine sins mentioned above including economic sustainability, consumer choice, and/or public health consequences (Fox et al., 2018). Fraud can occur at every pass of custody in the FASC, from large multinational companies involving importers to individual restaurants or grocery stores. Following are the frauds in detail identified from the literature review to be addressed. Various frauds are reported at different nodes from the FASC as shown in Fig.12.

3.5.6 Mislabelling

Another major issue of concern commonly occurring in the FASC is mislabelling of the fish and fish products (Luque & Donlan, 2019). A major global study revealed that at every stage of the FASC, fish mislabelling had been identified, right from the point of landing through to processing, distribution, retail, and catering (Oceana, 2016). Moreover, a study reviewed more than 200 published studies on fish fraud from 55 countries worldwide and found that, on average, 20 % of all fish samples tested were mislabelled (Ocenia, 2016). Fish mislabelling is an important enabler of illegal, unreported, and unregulated (IUU) fisheries with an average mislabelling rate worldwide of 34 %, (Warner et al., 2016; Helyar et al., 2014; Xiong et al., 2016). Similarly, in a study of ethnic fish on the Italian market, samples labelled as squid were identified as toxic species of puffer fish (Tantillo et al., 2015).

3.5.7 Species substitution

Species substitution takes place when low-value or less-desirable species of fish are exchanged for more-expensive varieties, for example, the fraudulent marketing of farmed salmon as wild-capture species (Cawthorn et al., 2015; Gordoa et al., 2017; Meloni et al., 2015) or as an example, Asian catfish, also called as Pangasius, has a neutral or almost no flavour and can be easily sold at a very low price, making it a perfect candidate for seafood fraudsters (Huang et al., 2014).

Several fish species are similar in appearance, taste, and texture makes it difficult to identify after being processed or prepared for consumption and presented with flavouring (e.g. in sauces or batter). Moreover, when a high-value species is marketed as a low-value species to avoid taxation, such activities are identified as major fraud (Reilly, 2018). Furthermore, it also occurs to conceal the geographical origin or to hide an illegally harvested protected species or a species from a protected area (Bréchon et al., 2016; Luque & Donlan, 2019). However, different fish species often belong to different value chains from catch to consumption the substitution of species takes place throughout the value chain (Jensen et al., 2010). In 2015, an INTERPOL-Europol investigation demonstrated that fish traded internationally was the third highest-risk category of foods with the potential for fraud, while in 2013 the European Commission classified fish in the second-highest category for fraud (Reilly, 2018). For instance, some hotel/restaurant businesses commit fraud by serving such cheap fish species instead of more expensive and exotic fish species like sole or halibut, or haddock and pollock are sold as Cod, Catfish as sea bass or sole, and tilapia as snapper is common fraud observed (Almerón-Souza et al., 2018; Cawthorn et al., 2015; Chin et al., 2016). Fraud in other fish species like tuna is even more extensive due to the vast differences in price of different species of tuna (skipjack, yellowfin, albacore, bigeye, bluefin) and their similarity when they are processed (e.g., canned tuna) (Johnson, 2014). Few other samples of aquatic species, sold as prawn balls in Singapore often found to contain pork and no traces of prawn (FishWatch, 2019).

3.5.8 Species adulteration

Species adulteration involves the addition of a non-declared, non-specified species to a primary processed raw material (fish), e.g. adding a lower-value species such as Coley or Saithe to high value frozen block of Atlantic Cod (Liou et al., 2020; Manning & Soon, 2014). The motivation behind such type of fish fraud is to exploit the considerable price difference between different species or to bring in raw material of unsavoury or prohibited origin into the FSC (Jennings et al., 2016). Moreover, fish products can be adulterated with additives and chemicals such as fertilizers, pesticides, antibiotics, hormones, veterinary drugs, colorants, and preservatives to enhance either production or food quality or 'hide' other types of seafood fraud (Mohanty et al., 2013). This type of fraud has been reported throughout the

AFSC, mostly during primary production, processing, and handling stages on the farm and during transport (Mohanty et al., 2013).

3.5.9 Illegal, unreported, and unregulated (IUU) substitution

Illegal, unreported, and unregulated fishing (IUU) contributes to fish fraud in which fish caught are illegally marketed and laundered through the legal AFSC. This allows brokers to integrate supplies and increase profits from different sources to achieve their orders in a fully exploited and limited resource market (Cook, 2018; Schmidt, 2005; Xiong et al., 2016). IUU has been reported as a rising concern in total European Union imports with about 10 % of the total value of fish (Olsen et al., 2019). IUU fishing is promoted by nations that provide flags of convenience, and relaxed import and export regulations. Thousands of fishing boats that would be illegal in their home nations lack transparency and traceability thus supplying fish during transportation (Cawthorn et al., 2018; Helyar et al., 2014; Schmidt, 2005). Additionally, the complex nature of the global FASC, where fish are transported through one or more intermediary countries for post-harvest processing and re-export to other countries, provides multiple opportunities for the mixing of illegally sourced fish with legally sourced, where they subsequently enter international trade as a 'legal' product of the exporting nation (Pramod et al., 2014).

3.5.10 Undeclared product extension

This involves the use of technology by AFSC actors like processors to increase the perceived weight of the seafood content for economic gain using treating, (e.g. over-breading or over-glazing), soaking fish in a brine solution, injecting undeclared chemical additives to increase the muscle's water holding capacity etc. (Jennings et al., 2016). Undeclared product extension has been reported as a common practice, which may also pose a public health threat. For instance, injection of gelatin-like chemicals, derived from animal skins and bones, into prawns and shrimp in China has been found (Fox et al., 2018). This further poses the consumer with uncertain human health threats linked to long-term intake of unknown chemicals and industrial substances in this economic fraud (Wu et al., 2013).

3.5.11 Chain of custody abuse

Chain of custody can be identified as the chronological document of the fish product which mentions the seizure, custody, control, transfer, analysis, and disposition of evidence (Fox et al., 2018). This document is required as part of traceability procedures and certification processes (e.g. eco-labels or Marine Council Stewardship certification) (Olsen & Borit, 2013; Pramod et al., 2014). The AFSC stakeholders such as traders and agents execute the alteration of this document to a gain monetary advantage (Mohanty et al., 2013). The global and complex nature of the AFSC with multiple nodes has enabled a frequent opportunity for chain of custody abuse. These nodes include fishers and aqua culturists, transshipments, distributors, warehouse owners, wholesalers, retailers, brokers, big trading companies in different countries, and, others, all capable of abusing and tampering with the traceability documentation (Jacquet & Pauly, 2008; Pramod et al., 2014).

3.5.12 Catch method fraud

The consumer considers the ‘wild’ species as a superior standard to the farmed species and prefers a higher price (Bronnmann & Asche, 2017). Catch method fraud contains the mislabelling of the type of production or harvesting method with monetary intentions. For example, line-caught fish attract a higher market value than trawled fish so maybe mislabelled to get a superior market price (Sustainable Seafood Coalition, 2016). A UK study involving 100 samples from retailers, identified that 15% of ‘wild’ salmon, 11% of ‘wild’ sea bream, and 10% of ‘wild’ sea bass were farmed and not wild as claimed (Jacquet & Pauly, 2008). This frauds are commonly seen at the processing and manufacturing supply chain stages by agents, middlemen, or final retail customers before sale to the consumer (Jacquet & Pauly, 2008).

3.5.13 Animal welfare fraud

A new and unconventional fraud has been revealed by food authenticity experts related to the sale of food with valuable animal welfare marketing claims e.g. written as Animal friendly (Fox et al., 2018). Several consumers consider animal welfare aspects to their food choices, which offers a competitive advantage of increased market value (Jennings et al., 2016).

3.5.14 Modern Day Slavery

Modern-day slavery is a crime and is illegal throughout the world, which defines a situation when any person is forced to work by ownership or control of an ‘employer’ through mental or physical threat or abuse, dehumanized when treated as a commodity or physically constrained on freedom of movement (ModernSlaveryAct, 2015). It is a quality attribute by consumers when a food produced comes from high standards of human welfare which enhances brand reputation and offers a competitive advantage for a premium price to any business. The reduced expenses on wages and health and safety procedures of the workers through fraudulent claims give a financial advantage to the AFSC stakeholders, whereas undetected modern-day slavery in the AFSC deceives the consumer (Ratner et al., 2014; D. Wu et al., 2013). The AFSC has been ill-famous and accused of displaying modern-day slavery with exposure of workers to a greater risk of injury, death, and other human rights abuses (Jennings et al., 2016; Ratner et al., 2014). For example, a report by Roberts, (2010) of 1039 fatalities from 1948 to 2008 on UK fishing vessels which were unstable, overloaded, and unethical. Similarly, a succeeding report has highlighted that in the UK fishermen continue to find employment via agencies in the Philippines and Ghana, are not paid the originally contracted wages, and experience poor working conditions on arrival (The National Crime Agency, 2015).

3.6 Shrimp production scenario and trends

3.6.1 Global trends in shrimp

Shrimp is the most produced and traded fish product globally with major production taking place in Asia and Latin America while the United States of America, the European Union, and Japan being the major markets (Shrimpinsights, 2023b). Major markets such as the US and Japan primarily import warmwater species from major producers such as India, Indonesia, Thailand, and Viet Nam. Whereas, the EU imports warm water species from China and Ecuador, and cold water species largely from Greenland capture fisheries (FAO, 2022). It is seen that global exports of shrimps and prawns are worth USD 24.7 billion with 16.4% in total value terms globally (FAO, 2022).

Import

In 2023 global shrimp production has been impacted by various issues such as a rise in production cost, low ex-farm and import prices, global weakening of economies in several major developed countries, and inflation which led to a fall in consumer demand for shrimp was seen in especially the North America and EU along with Australia and Japan (Shrimpinsights, 2023b). This same period noted a decreased import of 21% year-on-year in the combined top five markets (the United States of America, China, the European Union, Japan, and the Republic of Korea) at 675 000 MT (Shrimpinsights, 2023b). On the contrary, China noted a record high import of shrimp touching over a half million tonnes mark in the first half of 2023, with a 46.5 % rise in imports year-on-year at 538 430 tonnes with monthly imports ranging from 80 000 to 90 000 tonnes (Shrimpinsights, 2023b). Many shrimp-producing countries such as Viet Nam (approx. 31000 tonnes) and Thailand (approx. 15000 tonnes) imported shrimps to keep up the processing well supplied, mostly imported from India (Shrimpinsights, 2023b). Countries such as the UK also showed a lowered imports of shrimp by 14% (16565 tonnes) with fewer supplies from Ecuador, India, and Viet Nam, but increased imports from Iceland and Bangladesh. These shrimp imports included 40% value-added shrimp products. A steep decline in consumer demand for shrimp was also seen from Japan with a 17% reduction at 12645 tonnes (Shrimpinsights, 2023b). Similarly, EU shrimp trade was weakened too till June 2023 with a 9% fall in imports at 374 180 tonnes. The decline in import of processed shrimp was higher at a 20% reduction (51 200 tonnes) during this period.

Exports

The combined exports from all top 6 exporters (Ecuador, India, Indonesia, Vietnam, Thailand, and China) showed a slight growth in Q1-Q3 in 2023, at 187000 tonnes from 185 tonnes in 2022. Ecuador was the top exporter of shrimp in the global market with a boost of 24 % year-on-year (306 162 tonnes) worth USD 727 million. However, the value gain was lower at 5 % linked with deteriorating shrimp prices globally. China was the top importer of Ecuador shrimp with a 64 % share in total exports from 56 % one year ago. India, the second top exporter noted an increase in export in the first quarter of 2023 with higher exports to China (10% of total imports in China), Viet Nam, and Japan with surprisingly there was a decline in imports to the US for Indian shrimp (Shrimpinsights, 2023b).

The emerging markets, particularly China, are increasingly important targets for exporters and marketers of shrimp, whereas the scope for further growth in the traditionally developed markets is limited (FAO, 2021b). The aquaculture shrimp sector, which supplies the majority of volume to the global market but has also suffered from the impact of disease outbreaks and price variations associated with the boom-and-bust cycle (Hamilton et al., 2018; Global Trade Magazine, 2022). An increase in Chinese imports, to a large extent attributable to a crackdown on illegal (and unreported) smuggling of shrimp via intermediary countries such as Viet Nam, has supported increases in export revenue for Ecuador in particular (FAO, 2022). In terms of total stacked value (USD million), India is a leading exporter of shrimp followed by Ecuador, Vietnam, Indonesia, China, and Thailand. However, in terms of total stacked volume (1000 tonnes) Ecuador was the highest followed by India, Vietnam, Indonesia, China, Thailand, and Argentina.

3.6.2 Indian shrimp market trends

Overview

India is the second largest exporter of shrimp followed by China, and the third largest producer of shrimp followed by China and Ecuador in the world (FAO, 2021b; MPEDA, 2023). White-leg shrimp (L. vannamei) commonly known as pacific white shrimp is majorly produced and holds the largest export market share of India. It is popular among producers due to its fast growth rate, high reproductive capacity, and adaptability to different aquaculture systems which lead to increased production and better quality (Krishnan & Babu, 2022; Salunke et al., 2020). Whereas with the accelerating demand for shrimp around the world India has managed sustained growth due to its competitive pricing, high-quality produce, and compliance with international food safety standards contributing significantly to the overall expansion of the Indian shrimp market (Salunke et al., 2020). The Indian shrimp supply chain (ISSC) includes several nodes/stakeholders: feed mills, hatcheries, farmers, middlemen and commission agents, processors, exporters, and retailers.

Indian states of Andhra Pradesh, Gujrat, and west Bengal are the top shrimp producing states of India (DoFGI, 2022). Along with L. vannamei, Penaeus monodon (black tiger shrimp) is a popular shrimp type in India (BCG, 2020). However, among these two L. vannamei shares the highest share in shrimp production in India and is the primary driver of market growth, and the state of Andhra Pradesh is a major producer. Whereas P. monodon is majorly produced in West Bengal. The shrimp exports from India consist of raw L. vannamei, raw monodon, and value-added vannamei and monodon where, L. Vannamei consists of 80% of total export in 2023, followed by monodon with 5% of total export, and the combined value-added shrimp (L. vannamei and monodon) consist of 9% of total export (Shrimpinsights, 2023).

Production

India produced 902,525 tonnes of shrimp in 2022 which was a slight decline from 2021 production of 930,000 tonnes due to the reduced demand globally (DoFGI, 2022).The Indian shrimp market size is noted to reach USD 8.3 Billion in 2023 with the potential to touch USD 20.9 Billion by 2032, with a growth rate (CAGR) of 10.6% during 2024-2032. In 2023, India produced 296 700 tonnes of raw frozen shrimp (shell-on and peeled) by volume as compared to 2022, but declined significantly for processed shrimp with a 30% reduction year-on-year (22 100 tonnes) due to dropping demand in the top markets of the US and Canada (Shrimpinsights, 2023a).

Exports

India is consistently one of the top exporters (Second after Ecuador) of shrimp in the world as of September 2023 with 19% of growth as of 2023 year-on-year (Shrimpinsights, 2023b). India noted an increase in export in 2023 with a 3 % increase in exports to China (10% of total imports in China) at 104819 MT, and other Asian markets such as Vietnam with 3% increase (33860 MT) and a 6% drop to Japan (17584 MT) year-on-year. Despite a drop of 17.7% in export to its top market USA in 2022, there was noted stability and a slight increase of 1% in exports in 2023 (214044 MT) however exports to Canada declined by 5% (14522 MT) (Shrimpinsights, 2023b). Indian exports to the EU showed a drop of 12% (38119 MT), where the Netherlands and Belgium were the top markets at 7905 MT and 15088 MT respective volumes of exports. Although the export to Belgium showed 16% growth, the drop in Netherlands was 15% year-on-year, and a huge drop in the EUs third biggest market France by 54% (Shrimpinsights, 2023b). Moreover, there was an 80% boost in exports to ‘other EU’ countries such as Russia with 16.77 MT while a 7% decline year-on-year with 11147 MT. The decrease of Indian shrimp exports overall thus caused L. vannamei seeds demand to decline by 35% Indian shrimp farmers to reduce pond stocking and processors to decrease export processing due to falling market price (Shrimpinsights, 2023b).

Challenges in the Indian shrimp industry

Diseases

Despite the high growth rate and production, the Indian farmed shrimp industry faces several challenges and needs to overcome for their future growth and industry's profitability. One of the major challenges in the current Indian shrimp sector is the increased disease outbreak risk and low survival rates of shrimps (55%) which is substantially higher than other competitors such as Ecuador etc. (Alavandi et al., 2019). In particular, disease such as White spot syndrome virus (WSSV) is the common cause of concern for shrimp (K. F. Liu et al., 2009; Otta et al., 2014; Senapin et al., 2010)

Lack of world-class infrastructure

India has limited capacity in value-added processing to shrimps due to which about 28% of exports are sent to Vietnam for further processing and re-export which is a loss of big revenue for the country (Rubel et al., 2020). Second, government initiatives are required for the development of sufficient infrastructure such as labs of EIA (Environmental Impact Assessment), and MPEDA (Marine Products Export Development Authority) approved labs for disease diagnosis which would impact larger-scale production and safeguard the overall financial losses for all the stakeholders (Juditstarlin & Jothi, 2021). Thus, a dependable infrastructure is highly essential for disease diagnosis and quality control of shrimp.

Price volatility

Price volatility is seen as a burning issue for shrimp farmers as the overall industry struggles with low farm gate prices and high input costs. Lower margins have been impacting the economic viability of shrimp farming. Due to the decline in global demand from the top importing countries like USA Indian shrimp exports have shown a negative growth in 2022 as compared to 2021, which if continued would affect the overall health of the sector.

Lack of traceability

Lack of traceability in the traditional complex supply chain is another major challenge in ISSC due to the lack of infrastructure for traceability in place (De Jong, 2017). The demand for traceability is backed by a fast-growing niche market for sustainable and traceable seafood, thus some companies are seen starting to exploit this trend monetarily (Salunke et al., 2020). Currently, most of the farms are small and fragmented and thus not registered due to which there is a lack of government monitoring, which leads to a lack of efficient traceability (Salunke et al., 2020).

Lack of transparent supply chain

Lack of transparency in the sector is an outcome of several factors such as lack of coordination among stakeholders, dispersed and fragmented farm locations(Holger et al., 2020), which gives a scope for middlemen to intervene and manipulate the market wherever possible (Rubel et al., 2020; Juditstarlin & Jothi, 2021). Lack of transparency also reduces the interest of investors and creates a scope for frauds such as species adulteration where a bulk mixture of shrimp products from various unregistered farms are mixed with registered and certified farms, to be sold together as certified (Rubel et al., 2020). Such instances make it more difficult to identify the source of contamination or diseases (Okocha et al., 2018).

Detection of antibiotics in exports

Another crucial challenge that ISSC faces is the use of antibiotics by farmers as preservatives for shrimps knowingly and unknowingly as the majority of shrimp farmers are small-scale farmers who lack knowledge or information on good farming practices, especially in diseases outbreaks instances (Srinivas & Venkatrayalu, 2016). To help the growth of shrimps and reduce the mortality rate, farmers choose traditional ways to counter the issue by use of antibiotics which happens to be identified in export offshores (Salunke et al., 2020). Thus, the use of antibiotics is related to the lack of farmers' training.

CHAPTER 4: Stakeholders Perceptions of Blockchain Adoption in the Indian Shrimp Supply Chain

This chapter explores shrimp supply chain stakeholders' experiences, expectations, and opinions about the adoption of BT. It explores the current challenges identified through the stakeholders' perceptions and potential solutions to them. Further, it explores stakeholders' views on the benefits and costs of BT adoption in the Indian shrimp supply chains (ISSC).

The chapter is organised into four sections as follows. The first section introduces the background of the current status of FASC, focuses on ISSC challenges, and the need for BT to address these challenges, and provides the aims and objectives of the study. The second section describes the methodology used in this study followed by the third section, which presents the results of the qualitative study. Section four discusses the results of the study, and provides implications for businesses and policymakers, followed by future research directions.

4.1 Introduction

4.1.1 Background

Globally, shrimp is the most produced and traded fish product (Shrimpinsights, 2023b). However, shrimp is the most common seafood species implicated in seafood adulteration (Lawrence et al., 2022). The shrimp supply chains (SSC) are long, complex, and often opaque, resulting in a lack of visibility, making it harder to handle food safety concerns, verify product legality, and comply with export standards (Stirton, 2020). This complex and vague SSC generates scope for fraudulent activities arising from difficulties in surveillance (Islam et al., 2022). Several frauds in the seafood sector, including shrimp, have affected the trust and confidence of consumers and regulatory bodies (FAO, 2017; Kamilaris et al., 2019; Luque and Donlan, 2019). Moreover, end consumers are gradually becoming more demanding and want to be more informed, not only about the nutritional values of the products they buy but also about their origin and the sustainability standards along the value chain (Cruz & da Cruz, 2020). Thus, it is essential to keep track of the entire fisheries value chain activities, from wild capture or farm production to the supermarket shelves (Di Vita et al., 2022).

Thus, there is always a high risk to consumers with exposure to several health hazards due to the use of banned chemicals, antibiotics and harmful pathogens (Hamilton et al., 2018; Aya et al., 2021). Therefore, importing countries such as the EU have made mandatory labelling regulations for non-EU exporters of seafood, including shrimp, to provide details of details such as product name (commercial and scientific names), production method (cultured or wild catch), origin of the product, nutrition etc. (CBI, 2024; Directorate General for Health and Consumers, 2017). At the same time, the US has made mandatory labelling regulations for any seafood imports, such as the name of the product, name and location of the business, country of origin, allergen disclosure, ingredients, and HACCP standards (eCFR, 2024; FDA, 2024). Furthermore, any seafood exporters to both the EU and the US need to comply with strict regulations on the presence of maximum residue levels (MRL), which must not be exceeded by 150 ppm for sulphites, and 0.1 ppm for veterinary drugs in EU whereas, for the US its maximum 100 ppm sulphites and up to 2 ppm veterinary drugs (CBI, 2024; eCFR, 2024; FDA, 2024). In addition, they mandatorily need to have a system in place in processing and upstream supply chain where stakeholders need to maintain a proper cold chain and hygienic storage facilities, and the requirement to prove seafood products coming from non-IUU standards, with social compliance and sustainability certifications approved by competent authority (CBI, 2024; Directorate General for Health and Consumers, 2017). Hence, shrimp exporters must mention the origin (wild or aquaculture), when, who, how, and where it was captured (or raised), transported, stored, transformed, etc., which is identified as the competitive advantage of the sector (Fox et al., 2018; Cawthorn et al., 2018; He, 2010).

In Indian context, despite the remarkable growth, Indian SSC faces several issues, such as a lack of traceability and end-to-end visibility in the supply chain. (Holger et al., 2020)One significant challenge faced by the Indian shrimp industry is the identification of antibiotics in shrimp. (De Jong, 2017; Salunke et al., 2020)This impacts shrimp exports overall, often resulting in the ban on Indian shrimp in international markets such as the US and Europe (Handbook of Fishery statistics, 2020). Furthermore, such incidents initiate arguments on the food quality and safety concerns of Indian shrimp. (Khan and Lively, 2020; News21, 2011). Therefore, such instances affect consumer confidence in the credibility of the supply chains. Moreover, the non-transparent supply chains make it difficult to produce efficient traceability information in incidents of food recalls and rapid identification and response to food safety issues due to contaminations (Khaksar et al., 2015). Therefore, to safeguard the confidence of different stakeholders, including consumers and regulatory bodies of food safety and quality, and to efficiently impose regulations to combat risks with production methods and geographic origin of products, there is a need for a sustainable trustworthy system in place, which is tamper-proof and efficient such as BT (Jacquet & Pauly, 2018; Ringsberg, 2014).

These issues are common across SSC worldwide, including the top shrimp-producing and exporting nations such as India, which is the second largest exporter of shrimp, followed by China, and third largest producer of shrimp, followed by China and Ecuador in the world (FAO, 2021b; MPEDA, 2023). Despite such large production and export, ISSC faces several issues, as discussed in the 3.2 section of chapter 3. Therefore, this shows an immediate need for technological solutions to the existing matters discussed above and has become essential to explore solutions through the lens of emerging technologies such as blockchain technology (BT), which promises enhanced traceability while enabling security, trust, and efficiency in the SSC operations (Blockchain: Re-Imagining Seafood Traceability in Aquaculture, 2021). BT pledges to build the trust and better coordination among SSC stakeholders, who currently lack an efficient, trustworthy and transparent traceability system in the current complex supply chain network. Furthermore, the BT traceable systems show the potential to provide more real-time information throughout the supply chain, which would help to combat fraud and reduce dependency on middlemen (Čapla et al., 2020; Lawrence et al., 2022).

However, current literature shows that there is a significant gap in terms of empirical studies on current challenges in the ISSC and the adoption of BT to solve these issues, especially in one of the top shrimp exporters in the world (ByteAlly, 2019; FAO, 2020; Financial Times, 2019; Juditstarlin & Jothi, 2021; Ramraj, 2019; Salunke et al., 2020; Srinivas & Venkatrayalu, 2016). Secondly, there is inadequate literature available to investigate the opinions and perceptions of ISSC stakeholders on emerging technologies adoption such as BT, including the benefits and costs of BT to the sector (BCG, 2020; Holger et al., 2020; Salunke et al., 2020; Srinivas & Venkatrayalu, 2016). Thus, this study makes an effort to fill these gaps and would be helpful to businesses, providing guidance to researchers, businesses, and policymakers who are exploring SSC and the sector to consider the adoption of innovative technologies such as BT. Therefore, it is essential to investigate the current underlying challenges faced by Indian SSC stakeholders and explore their perceptions and views on BT adoption as a potential solution to the identified ongoing challenges in the SSC.

4.1.2 Aims and objectives of research

The main aim of this research was to explore in-depth expectations and opinions of ISSC stakeholders, such as fishermen, farmers, hatcheries, processors, exporters, retailers, traders, etc., about the implementation of BT in the sector. This study has the following three objectives: to (i) explore in-depth the current challenges affecting SSC in India, (ii) identify and discuss possible solutions related to challenges in the sector, and (iii) explore and discuss the benefits and costs of BT adoption in the ISSC.

4.2 Methods

4.2.1 Exploratory research: In-depth interviews

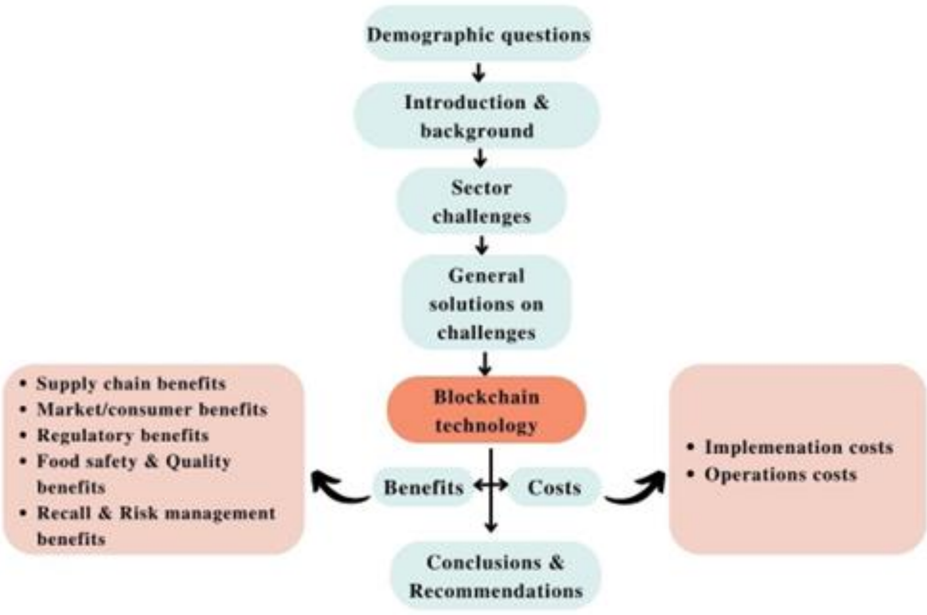
This study was conducted using exploratory research based on a qualitative data collection method. This approach helps to develop detailed research on the topic, providing in-depth and rich context information. Therefore, this approach was chosen due to the lack of literature investigating BT adoption in the ISSC. In addition, the exploratory research method was selected as it helps to assess the complexity and vast diversity of the sector experts' experiences along with their perceptions and opinions to collect a piece of in-depth information rather than an insufficient amount of data from large samples (Myers, 2009; Theerachun, Speece and Zimmermann, 2013). Moreover, the exploratory research approach offers in-depth and context-rich information, and thus, it is considered effective in providing guidance and generating hypotheses for further research (Myers, 2009).

The in-depth interview method was chosen from the different types of qualitative research methods as it is considered one of the best methods to collect information on individuals' perspectives, expectations, and experiences (Asioli et al., 2016), which further allows the use of some pre-formulated questions, that covers the topics that are expected to be discussed (Malhotra & Birks, 2007). An in-depth interview is "an unstructured, direct, personal interview in which an experienced interviewer probes a single participant to uncover underlying motivations, feelings, and beliefs on a topic" (Malhotra & Birks, 2017). However, a semi-structured qualitative interview schedule format was used due to its flexibility and validity being the most widely used interviewing format for qualitative research (Asioli et al., 2016). Moreover, other advantages of this method include the privacy of interviewees to freely speak on their thoughts, experiences and motivations through such a face-to-face setting, and clarify their points with the researcher confidently (Rowley & Slack, 2004). Therefore, this method was found suitable for ISSC stakeholders to capture their experiences and views on current challenges and potential solutions to them in the sector, followed by the perceptions and opinions on BT-enabled traceability adoption in the current SSC.

The semi-structured qualitative interview schedule included a predetermined semi-structured list of questions and topics, and the researcher could ask other questions depending on emerging topics from the interview(DiCicco-Bloom & Crabtree, 2006). This allowed researchers to be in a good position to adjust probing questions according to each participant's circumstances and experiences (Asioli et al., 2016).

4.2.2 Structure of the semi-structured questionnaire

As described in Figure 12, the structure of the questionnaire was designed as follows. Beginning with a series of ice-breaking questions such as the business location, size of the business (no. of employees), their role in the company, sector experience, and role within other business partners (other stakeholders in direct contact). Next, they were asked to list and elaborate on current challenges in the shrimp industry, followed by the identified potential solutions to these challenges. Third, they were questioned on their knowledge of BT; the interviewer introduced the interviewee to BT and later explored their perceptions of BT as a solution to the challenges. Next, they were asked to share thoughts on the benefits and costs of BT in SSC identified from the secondary data on the topic.



(Source: Created by author)

Figure 12-Structure of the questionnaire

Benefits of BT included- supply chain benefits (*i.e. trust among stakeholders, reduced transaction costs, and better coordination among all SSC stakeholders*), consumer and market benefits (*i.e.an increase in consumer trust in SSC and access to new markets*), regulatory benefits i.e. *reduced seafood frauds, and improved regulations by government on traceability etc*.), food safety and quality (*i.e. improved safety with real-time monitoring by BT, and enhanced traceability*), and recall & risk management benefits (i.e. *increase in recall management efficiency*). Whereas the Costs investigated included- implementation and operations costs.

4.2.3 Participants recruitment

The ISSC consist of a few big players (with their own farms, processing, and exporting units) and several small and medium-sized exporters, processors, traders, hatcheries, and farmers (Salunke et al., 2020; Sivaraman et al., 2019). Thus, given the objectives of the study, business owners/managing directors, production managers (in case of processing plants), and operations managers (in case of hatcheries/feed companies) were chosen as participant stakeholders as the best respondents. They are the ones responsible for managing major business activities such as operations, production, marketing, sales, etc. thus they were most likely to have in-depth market knowledge, especially on challenges in the sector, and to share their perceptions on potential solutions to challenges, and BT adoption in the SSC.

Purposive non-stochastic sampling was observed to recruit participants in this study to retrieve information from stakeholders with specific sector knowledge who could highlight the relevant contemporary challenges. In addition, the snowball sampling procedure, also known as respondent-driven sampling or chain referral (Baltar and Brunet, 2012; Lune and Berg, 2017; Gile et al., 2017; Malhotra and Birks, 2017), was used to recruit participants from the Indian shrimp industry. Extensive research was conducted to determine the most suitable respondents to answer the study research questions. The researcher drew a list of contacts through direct approaches to the individuals, businesses via known contacts and social media site LinkedIn, and other sources such as Exporters directory available on website of Marine Product Export Development Authority (MPEDA[7]). As mentioned previously, stakeholders in the businesses from different parts of the SSC such as hatcheries, feed producers, aquaculture farmers, traders, processors, exporters, retailers etc. were approached.

In total, 270 stakeholders of SSC from various sources were approached. In total, twenty-three interviews were administered during April – June 2022 (Table 2). Twenty-three participants were found enough due to the onset of data saturation wherein no new information or themes were found. Thus the richness and depth of data obtained from these 23 participants was found sufficient to answer the research questions. The stakeholders (participants) were divided into three different categories for convenience based on their role in the supply chain, such as pre-production, production, and post-production activities.

[7] MPEDA- MPEDA is the nodal agency for the holistic development of seafood industry in India to realise its full export potential as a nodal agency (https://mpeda.gov.in/).

Stakeholders from feed companies, and hatcheries were categorised in ‘pre-production’(4), farmers/fishers (7) were being the producer were under the ‘production’ category. In contrast, traders/wholesalers, processors, exporters were part of the ‘post-production’(12) category.

The highest number of stakeholders were seen from Andhra Pradesh, Telangana state, and Maharashtra. It was likely to have the majority of stakeholders from these states as these are the top shrimp producing states of India (Salunke et al., 2020; Srinivas & Venkatrayalu, 2016). It is worth noting here that several stakeholders were noted to have more than one business activity in the shrimp supply chain (See Table 3). Excluding some farmers, the majority of the interviewees mentioned being involved in more than one business activity in relation to shrimp or other fish, such as having a farm and a hatchery or being a processor as well as an exporter, or in one case both exporter and importer.

Reflective Analysis on participant selection, self-selection bias, and representativeness

Among all the stakeholders initially approached (270), only 23 agreed to participate in the study. While thematic saturation was achieved, the low participation rate raises the potential for self-selection bias, in which individuals with a strong interest in or favourable perception of BT may have been more inclined to participate. Self-selection bias, a common challenge in social research, happens when people choose to participate based on personal motivations, potentially skewing the sample and making it less representative of the wider population. However, it is worth noting that the period of interviews was also the shrimp harvest season in India, making it more difficult for the stakeholders to find time to participate in this study. For this reason, the majority of them despite their interest to participate in interviews, refused to participate due to their busy schedule. In the context of this study, it is possible that those who already support or are engaged with BT in the fisheries and aquaculture sector felt more inclined to participate, while those with reservations, lack of familiarity, or neutral views may have declined, thus creating a potentially skewed representation.

This sample may also place a uneven focus on prospects highlighting the potential benefits of BT, potentially leading to findings that appear more favorable toward its adoption. Research on emerging technologies often draws early adopters or those who see clear benefits, which can result in the underrepresentation of more critical or cautious perspectives (Rogers, 2003). As a result, themes like trust, transparency, and traceability may dominate the findings, while perspectives on challenges such as costs, data privacy, or operational difficulties could be underrepresented.

Despite the lower response rate, the sample of 23 participants remains reasonably representative, particularly considering that thematic saturation was reached. In qualitative research, smaller samples are often appropriate for allowing detailed insights, and saturation where no new themes emerge in later interviews that support the sufficiency of this sample size (Guest et al., 2006). Moreover, the 23 participants came from diverse roles within the supply chain, which includes producers, processors, and regulatory authorities, offering perspectives from various viewpoints. This selection helped maintain balanced and varied data, despite the small sample size.

Table 2-Stakeholder profiles based on their roles, identified category and location in India

Stakeholder	Role	Employees	Location (City, State)	Activities	Direct business stakeholders
HATCH01	Director	16	Nellore, Andhra Pradesh	Hatchery and nursery unit	Seed companies (broodstock suppliers), farmers
HATCH02	Director	60	Chennai, Tamil Nadu	Hatcheries and PCR diagnostic	Seed companies (broodstock suppliers), farmers
HATCH03	Quality and Production Manager	15	Nellore, Andhra Pradesh	Hatcheries and nursery unit	Seed companies (broodstock suppliers), farmers
HATCH04	Managing Director	20	Bhimavaram, Andhra Pradesh	Hatcheries and Bio-floc consulting	Seed companies (broodstock suppliers), farmers
FAR01	Managing Director	30	Hyderabad, Telangana State	Shrimp farming	Feed companies, hatcheries, processors, & exporters
FAR02	Managing Director	50	Nellore, Andhra Pradesh	Shrimp farming	Processors, hatcheries, and exporters
FAR03	Farmer	30	Mudinepalli, Andhra Pradesh	Shrimp farming	Feed companies, hatcheries, and traders
FAR04	Managing Director	60	Hyderabad, Telangana State	Shrimp farming, hatcheries, and technology solution provider	Processors and farmers for hatchery business

FAR05	Managing Director	250	Vijayawada, Andhra Pradesh	Shrimp farming and hatcheries	Feed companies, processors, & traders
FAR06	Farmer	10	Raipur, Chhattisgarh	Shrimp and rainbow trout farming	Traders and agents, feed companies
FAR07	Farmer	08	West Godavari, Andhra Pradesh	Shrimp farming	Feed companies, hatcheries, processors
TRA01	Business owner	06	Hyderabad, Telangana State	Trading merchant- Shrimp & other fishes	Buyers, suppliers, farmers
TRA02	Partner	08	Vijayawada, Andhra Pradesh	Trading and hatcheries- Shrimp	Farmers, processors
TRA03	Trade Partner	15	Hyderabad, Telangana State	Trading, hatcheries and shrimp feed manufacturer	Farmers, processors, and exporters
TRA04	Partner	15	Mumbai, Maharashtra	Trading and retail fish shop	Exporters and some farmers
PR01	Managing Director	50	Nellore, Andhra Pradesh	Processing and export- Shrimp & other fishes	Importers/buyers, agents, some farmers
PR02	Managing Director	15	Panvel, Maharashtra	Processing & export- Shrimp	Farmers, Importers
PR03	Managing Director	80	Belapur-Navi Mumbai, Maharashtra	Processing & export- Shrimp & other fishes	Importers and agents

PR04	Managing Director	21	Cochin, Kerala	Processing- Shrimp	Farmers, agents, traders, local restaurants
EXP01	Managing Director	10	Hyderabad, Telangana State	Exporter- Shrimp & other fishes	Farmers/agents
EXP02	Director	10	Bhubaneshwar, Odisha	Exporter- Shrimp & other fishes	Farmers, processors, and importers
EXP03	Managing Director	18	Hyderabad, Telangana State	Exporter & Importer (Saudi Arabia) Shrimp	Suppliers, mediators/agents
EXP04	Production Manager	10	Malvan, Maharashtra	Exporter- Shrimps & other fishes	Farmers, importers
Note: HATCH-Hatchery owner; FAR-Farmer; TRA-Traders; PRO-Processors; EXP-Exporters.					

Table 3-Stakeholders involved in multiple business activities in the shrimp supply chain

Activities	Farming	Hatchery	Feed co.	Testing labs	Processors	Traders	Exporters	Importers
Farming	4	3	1	1	2	0	0	0
Hatchery	3	3	0	1	0	2	0	0
Feed co.	1	1	1	0	0	0	0	0
Testing lab	1	1	0	1	3	0	0	0
Processor	2	0	0	3	4	0	4	0
Trader	0	2	0	0	0	2	1	0
Exporter	0	0	0	0	2	0	3	1
Importer	0	0	0	0	0	0	1	1

4.2.4 Interviews procedures

Twenty-three interviews were conducted in which, apart from one female hatchery manager, all other participants were male. The interview schedule was sent to participants in advance along with the participant information sheet (Appendix D) and an introduction to BT called 'What is blockchain' (Appendix E) to give an overview of BT. In addition, interviewees were informed about the research objectives and were introduced to the interview structure prior to the start of the interview. Permission was asked to audio record the interview before the sessions (Arnould & Wallendorf, 1994). Interviews ranged between 40 and 55 min in duration. For suitability, the interviews were settled at the respondents' most suitable time and were conducted using Microsoft Team or Zoom by the researcher, while an assistant was accompanied to take notes. All the interviewees preferred online interviews due to the change in their nature of work, harvest season and remote locations in the case of some farms. Five interviews were video recorded, while eighteen were audio recorded. The interviews were conducted in English. These records were archived, and the audio recordings of the interviews were precisely transcribed using NVIVO and then iteratively read singularly to get a profound understanding of their meaning. The recordings were gone through from the beginning and worked through the content sequentially with spoken words verbatim, such as pauses, filler words, and non-verbal cues like laughter, sighs and interruptions. All participants shared informed consent, and the study was approved by a University of Reading ethical committee.

4.2.5 Data analysis

In this section, the results that emerged from the in-depth interviews are presented and divided into several sub-sections following the structure outlined in the semi-structured qualitative interview schedule. These sub-sections likely delve into specific themes, patterns, or insights that emerged during the interviews. A preliminary data analysis was done instantly along with and after each interview by identifying emerging themes and building preliminary conceptual maps from each interview by the interviewer (DiCicco-Bloom & Crabtree, 2006; Thorne, 2000). Summaries were written by the interviewer immediately after the interview and collated alongside the notes from the interview sessions. Thematic analysis was conducted to identify different themes identified from the interview and analyse respondent responses. Thematic analysis "is a method for identifying, analysing, organising, describing, and reporting themes found within a data set."(Castleberry & Nolen, 2018; Nowell et al., 2017; Yin, 2015).

All the recordings were transcribed into a text file, and transcriptions were read and re-read thoroughly along with the audio/video file to get to the get the precision of data (Castleberry & Nolen, 2018) . This was followed by a preliminary data coding to identify information related to the research questions using NVivo[8] 20.6.1.113 (QSR International) is a qualitative data management and coding software. Coding is a way of "indexing or mapping data, to provide an

[8] NVivo- https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

overview of disparate data that allows the researcher to make sense of them about their research questions" (Elliott, 2018, p. 2850). Codes were directly developed by examining the data through inductive coding for data analysis (Blair, 2015). This process is also defined as "data-driven" coding (Braun & Clarke, 2006). Coded information was re-read, where code names were redefined if required, and codes with similar meanings were merged. Once the data had been coded, themes were identified to include a series of similar concepts contained in the dataset under a single, more specific theme that could help to summarise the text (Nowell et al., 2017). Data saturation was reached after the twenty-third interview as the interviewer perceived no new information.

4.3 Results

This section showcases the results from the in-depth interviews with the stakeholders on the current challenges affecting ISSC followed by the potential solutions to the challenges, and finally discussing the stakeholders' perceptions on the benefits and costs of BT adoption in ISSC. All the relevant quoted statements from the stakeholders are presented under respective theme and sub-theme.

4.3.1 Perceptions of stakeholders on current challenges in the shrimp supply chain

The key themes and outcomes that emerged from the study on the ongoing challenges in the ISSC are presented in this subsection. Table 4 presents the themes and sub-themes that emerged, which were categorised under main four themes of quality and food control, management, economics, and information asymmetry and technology. Sub-themes highlight the crucial challenges underlined by the stakeholders.

Table 4-Current challenges in the sector

No.	Themes	Sub-themes
1.	Quality and food control	- Diseases - Antibiotics use - Fraud
2.	Management	-Long waiting time for port clearance -Middlemen -No coordination -Lack of training -Fragmented and small size farms
3.	Economics	- Dominance of big players -Reduced margin -Price fluctuation
4.	Information asymmetry and technology	

Quality and food control

Interviewees were aware that ISSC's economic success depends on the availability of excellent shrimp seeds and the quality and safety of the final product. Some stakeholders identified bad seed/broodstock quality as an important element of control, highlighting that the selling of low or bad-quality seeds by some hatcheries to farmers can lead to a high possibility of disease occurrence in shrimp.

> *"We have challenges of quality inputs (seeds). If farmer is suffering from bad quality of seed, then getting the good harvest is a challenge in production."*

Participants were also concerned about frauds which occur normally when shrimps of different qualities are mixed altogether. This happens because shrimps produced by farmers using different certifications such as higher quality shrimps with Best Aquaculture Product (BAP) are mixed with other non-certified shrimps to fetch premium prices.

> *"If he(trader) were supposed to buy the shrimp from us, he's buying from*

elsewhere and claiming that he has bought from our farm. So because if he claims that he has bought it from the from our farm, our farming is certified so it gets a very premium price." (FAR02)

Another challenging aspect mentioned by the majority of stakeholders was the control of diseases such as white spot syndrome, running mortality virus and yellow headed virus. These diseases are common in significant shrimp species produced in India such as *Penaeus vannamei* and *Penaeus monodon*. Perceived concerns for such pathogens were very high as shrimps attacked are not curable, infectious and as a result they can affect the production in farms of the whole village and those of surrounding areas.

"Main challenge is due to disease problems. The major disease threat is white spot problems. If your neighbour farmer get virus other will get like that whole village will get the virus and get in troubles." (HATCH01)

Stakeholders highlighted the identification of antibiotics in shrimps when they reach export destinations was a challenge faced by many exporters. It was observed that the use of antibiotics was linked to uneducated and untrained farmers who knowingly/unknowingly use preservatives that has antibiotic components in them.

"Farmers are not too much educated and trained properly. They use unknowingly antibiotics to prevent diseases and….which is good for growth of shrimp.. We cannot check every batch of shrimp but when it reaches to export countries they get rejected." (PR04)

<u>Management</u>

Stakeholders especially processors and exporters highlighted a key concern of long waiting time at ports for clearance which adds an extra cost to them and affects quality of product. This occurs due to a lack of efficient documentation system which is still mostly paper based.

"We need to wait for 2/3 working days. Until then, we need to manage our shipment and all that, but if you make a delay in time, they (shipping companies)

want their more waiting charges." (EXP01)

Another major concern highlighted by interviewees was the lack of coordination among all ISSC stakeholders. The long and complex supply chain makes it difficult to coordinate well among each other, and in some cases even with the immediate next node of the supply chain, for example, farmers and processors.

> *"No visibility is in-place as there is no particular mechanics in this market to coordinate well with other businesses. Because this is the buyer(processor) who buys shrimps from wholesaler and not from the farmer." (TRA04)*

The lack of coordination thus promotes the rise of middlemen, as mentioned by the majority of the stakeholders, as another critical major challenge in the industry. The lack of visibility in the system results mediatorsin dependency on middlemen who take a big chunk of profit margins. Whereas interviewees such as processors and some exporters raised the issue on struggle to make direct contact with farmers, especially small farmers located in remote areas, and thus have to rely on agents to get the shrimps with added costs of commission to the product.

> *"Because I cannot go to each and every farmer to find out what he has, & what he can supply. So, we in every area have lot of agents like mediators. I contact mediator, and mediator will take his commissions and his mediators again will have again another mediator." (EXP03)*

On contrary some respondents noted the importance of middlemen because they act as a mediator playing a key role among different parts of ISSC and are a vital part of the ecosystem.

> *"It's not possible to remove middlemen and I don't want them to be removed. Like that, if you have to buy something again, some broker or somebody has to be there in middle person means who should be reliable." (FAR03)*

Participants further highlighted the problem of lack of training for the farmers who are primarily responsible for the quality of the product. They lack awareness of the best practices in shrimp farms, such as how to handle new shrimp diseases that affect the overall production. This also was linked by some interviewees to the lack of government monitoring on these aspects of educating farmers who, as a result, make choices that affect overall ISSC, for example the use of antibiotics or selecting low-quality seeds/broodstocks.

> *"Most percentage of the farmers are still under the traditional farming methodology; they are not culturing shrimp farms in proper way. They don't have proper knowledge." (HATCH04)*

Another challenging aspect identified from the stakeholders was the fragmented and small size of farms in India, among which many are not yet government registered. Being unorganised, they lack awareness of trends and updated knowledge in the sector which promotes the rise of agents or middlemen due to the lack of coordination as discussed earlier.

> *"Our farmers all are scattered, very small ones, so they are tough to keep on the record or up to the mark" (FAR07)*

Economics

Stakeholders stressed another key challenge: the power of the big firms in the shrimp sector who influence the market and are responsible for the price fluctuations. It was identified that these large companies have had private coordination with their partner companies for many years. Several large companies in the ISSC have their own farms and processing plants, and they export shrimp themselves, which provides them with a competitive advantage over other small businesses.

> *"They (large businesses) have a lot of money, so they can control the whole system, but we can't." (Hatch 04)*

Reduced margins were also one of the crucial challenges highlighted by participants who were small businesses in the sector. They specifically mentioned two factors for reduced margins:

first, big players in the market manipulating prices for profits, and thus, other small businesses must compromise margins in the competitive market. Second, middlemen who take shares from the margins.

> *"Because of the competition from big companies on reduced rates, and agents take margins too…so you have to compromise your earlier margin" (FAR06)*

Additionally, some respondents discussed that issues such as price fluctuation result from the lack of government monitoring of prices. There must be stricter regulations for large companies from government bodies and mandatory registration and monitoring of all farms and hatcheries on the government database.

> *"Actually, government should take lead into this by efficient monitoring of price. All these hatchery licenses are not properly updated by government so far and all farmers are not registered yet. There's no efficient monitoring by government" (HATCH01)*

Information asymmetry and technology

Information asymmetry was one of the crucial challenges identified by the stakeholders where the big players have the advantage of access to more data on the production and processes compared to the smaller firms, as noted by some participants. This enhances the lack of transparency in the sector. Stakeholders such as farmers shared their concerns about having no information or visibility of the supply chain, especially on pricing.

> *"Farmers don't know what's happening to their product later. They have no data on this. They have no idea, what is happening, and the farmer is left in the dark." (FAR05)*

Lack of implementation of innovative technologies across the entire Indian shrimp sector, from testing facilities for seeds and broodstocks to handling shrimp during processing was another challenge highlighted by respondents. Furthermore, the higher frequency of antibiotics identification in Indian shrimps in the US and EU is due to lack of efficient labs to detect the use of banned antibiotics early to avoid losses.

> *"It will be mostly it (antibiotics) is getting detected after our shipment reaches the importing the export country and then there. Like in US or Europe, they have very top technologies and then they can detect even the minute quantity if its present. we don't have very good labs." (HATCH03)*

Respondents also mentioned the reluctance of stakeholders to accept technology due to a lack of knowledge and awareness, especially among farmers, who are noted as less educated and untrained. Many businesses are not ready for investments in the technology due to the higher cost involved.

> *"People still not excepting technology because they don't want to invest much on that in that, majority farmers are they don't have their own land, they mostly add on lease basis, so they don't go with this technology or infrastructure." (TRA03)*

4.3.2 Perceptions of stakeholders on potential solutions to the challenges identified

The key themes and outcomes emerged from the potential solutions to the challenges identified in the previous section are presented here. Table 5 presents the themes and sub-themes that emerged, which include mainly two broad themes- Empowering farmers and Research and innovation with various subthemes under them as described below.

Table 5- Potential solutions to the challenges

No.	**Themes**	**Sub-themes**
1.	Empowering farmers	*-Trained/educated farmers* *- Good collaborations among stakeholders* *- Government support* *-Removal of middlemen*
2.	Research and Innovation	*-Innovation/research in the sector*

		-Single-platform technology *-Stakeholders perceptions on BT as a solution to the ISSC challenges*

Empowering farmers

Stakeholders shared a common consent on empowering farmers through training and educating them on good farming practices, such as stocking density, choosing good quality broodstocks for export quality products, and understanding the market demand. These training would enable them to eradicate the top challenge of the sector, i.e., shrimp mortality due to diseases, and save financial losses.

> *"The farmer should also know how to select his seed and how to make his farming activities better. Farmers have to get developed, or else we have to make so many awareness programmes for the farmers so that they can control most of the things." (HATCH03)*

Good collaboration among all the stakeholders can build a good trust in the overall ISSC, which was another key solution that emerged from several respondents' responses. This included forming a cooperative society to bring small, unorganised farmers together to counter the price fluctuations and other challenges, such as the use of low-quality seeds and feeds and reducing the dependencies on agents. Collaborations with farmers who practice good aquaculture practices would bring more trust for the stakeholders, especially from the importing countries such as government agencies ,importers, and retailers.

> *"If you collaborate with good farmers, who don't use any antibiotics and those kind of unavoidable chemicals and antibiotics, what happens is the countries start trusting the seller and the exporting country, where the material is coming from. So, the country start trusting material you have qualified and in turn they would also start trusting the exporters also, similarly for processors too. So, this*

way it's a benefit for those who are seriously, you know, want to make a change." (FAR02)

One more vital solution that emerged from the discussion with participants was support from the government in the form of incentives for small farmers through cooperative societies, which would enhance the inclusion of small farmers into the main flow of the supply chain and provision of well-equipped laboratories to test the quality of products. Moreover, essential government intervention would play an essential role in monitoring the processes and having a check on price fluctuation too.

"Government intervention will definitely help solve challenges if technology is made mandatory or regulation Government has to get in touch of the small farmers, so they are organised that makes them some empowered." (FAR04)

Another important solution identified by the study was removing middlemen from the ISSC, which would enhance transparency and visibility in the supply chain.

The idea of having a single platform was found associated with removing middlemen. This would also provide direct access for stakeholders to each other, such as any processor could directly connect with farmers, saving the commissions taken by middlemen.

"Middlemen removal would be important for all as this will increase the profit margins for all and give more power to producer to set prices"

Some of the stakeholders were concerned about the removal of middlemen because it might be a difficult task without a robust replacement system that would serve the purpose of middlemen practically.

"Definitely, technology would connect us directly with farmers or other stakeholders without depending on middlemen. But removing middlemen is not easy unless there is a robust technology that is enough efficient." (EXP04)

Research and Innovation

Some respondents highlighted an advancement in the sector's innovation/research, such as finding new disease resistant varieties or using novel technologies to bring more automation in the ISSC. This was linked to a rise in investment in the sector and helped to increase shrimp production to fulfil the increasing demand for shrimp worldwide.

> *"There must be advanced research and lab facilities to bring disease resistant shrimp varieties, which would increase the volume of shrimp production." (HATCH03)*

Participants also commonly shared strong support for the use of single-platform technology, which was identified as one of the top solutions to the sector's problems. With the provision of such a platform for the whole ISSC, enhanced transparency and coordination among all in the sector would be promised, where all the stakeholders could share data such as prices and processes and have direct contact with the required stakeholders.

> *"If we can have a common platform to gather all these farmers where they can share their data. They can share their prices and, any exporter can have access to that particular data and directly contact them and get the information." (EXP03)*

A notable number of respondents knew about BT before the interview. However, the majority of them noted the source of information as the news on Bitcoin or cryptocurrencies. Several respondents expressed optimism about adopting BT to address challenges in the shrimp industry. Notably, the respondents cited the benefits of real-time data availability, which offers transparency and improved traceability across the entire supply chain. Many stakeholders viewed this feature as highly appealing.

> *"I think it can bring more visibility of processes, and this according to me it can even help in connections with farmers and to improve the visibility through transparency in the system. It will surely help if everyone is on single platform."*

(PR03)

Participants additionally indicated that BT would make the ISSC operations more efficient, whereas some of them perceived its importance for prompt forecasting of shrimp production and supply, for all business partners including farmers.

> *"When you have a project forecasting of the material (shrimp) required quantity and quality. It will be easier for all and also farmer's side." (TRA03)*

It was observed that stakeholders positively valued BT adoption to save commissions and profit margins taken by the middlemen due to the enhanced visibility of information securely and transparently, with trust in the ISSC.

> *"I think, currently these middlemen are earning a lot. Both farmer and consumer are losing. So blockchain can help in reducing this intermediation. If you are talking about linking transparency in the system, so middlemen are one who hides the information out there." (TRA03)*

Reduction in waiting time for containers at foreign borders would be another perceived use of BT by participants, where BT would simplify the documentation process with increase in confidence of the government authorities such as FDA[9] for swifter clearance of the shrimps.

> *I think, documentation process should be made simple with the use of technology. The technology cannot stop diseases, but if transparency comes in the system a lot of things get better for all. (EXP03)*

However, on the contrary, one of the respondents strongly mentioned the challenge in BT acceptance by the stakeholders. Stakeholders such as farmers need to be provided with incentives to motivate them to use BT.

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[9] FDA-United States Food and Drugs Administration (https://www.fda.gov/)

"I mean it can be a good solution for all the challenges you mentioned, but the problem here would be the acceptability. Like a processing plant should tell the farmer he if you log this data, I'll give you ₹10 per kg. Some incentive must be there." (FAR05)

4.3.3 Benefits of BT in the Indian shrimp sector

This section presents respondents' perceptions and beliefs about the benefits of BT adoption in ISSC. These are elaborated answers given in response to probed questions following their yes/no answers on the BT benefits (refer to Appendix-G). We categorised the benefits into three major categories as supply chain benefits, marketing benefits, and regulatory benefits.

Supply chain benefits

Several supply chain benefits were discussed with the respondents in the BT implementation scenarios in ISSC such as to bring better coordination among all stakeholders, reduced supply chain transactions costs and increase in trust among the stakeholders in the supply chain.

All of the participants well recognised the importance of better coordination among all the stakeholders, obtained through the transparency on trustworthy data available on a single platform, secured by BT. They identified that the visibility of the flow of material down the supply chain would help them easily coordinate with their business partners due to easy access to the data about other stakeholders on the BT platform.

"Yes, use of blockchain technology, will bring better coordination and visibility in supply chain. Transparency and visibility of accessing your data, for sure it will definitely have an impact in terms of coordination among each other. Like for example now see if I need black tiger shrimp, I can go to the blockchain application. I can see where the material (shrimp) is available of the black tigers (shrimps) because everybody has their information in the system." (TRA01)

Stakeholders' responses were mixed in terms of reducing transaction costs in the ISSC operations because of BT, as some stakeholders were not sure how BT adoption would impact transaction costs. Some other respondents mentioned that transaction costs will remain the same as transportation costs and other relevant costs will remain unaffected despite BT being adopted.

> *"Whatever transport cost or the material transportation cost, it will be the same, there won't be any changes in that cost." (TRA04)*

The participants responded positively, noting that BT provides a trustworthy, reliable mechanism to accurately record, view and validate transactions throughout the complex ISSC. Some highlighted that adopting BT would ensure the authenticity of shared information (e.g., sustainability certificates) with automated information flow, ultimately enhancing trust with other businesses with reduced risk.

> *"I can record and see exactly who is involved in the operations and verify all the certifications involved, certificate agencies without manual interference, and how authentic is the product this will increase trust among all bringing more clarity to business operations." (EXP01)*

In general, the stakeholders expressed a positive consensus on BT's ability to build trust in the ISSC. Immutability of data (i.e. restriction on any change of product data), which is stored on a decentralised and distributed BT platform, were identified as the primary factors contributing to this trust. Such efforts can lead to increased brand loyalty and confidence to do business, thereby fostering stronger buyer-seller relationships.

> *"I believe the blockchain will definitely increase the trust between everyone. Because of its nature of transparency, one cannot manipulate the product details, and the amount of information of shrimp from our processing plant, that is saved at the decentralized information cannot be manipulated once it is left the product processing unit." (PR04)*

Marketing Benefits

Respondents were seen hopeful for gaining marketing benefits such as increase in consumer trust, and access to new markets globally to the existing stakeholders because of the enhanced traceability and transparency promised by BT to the stakeholders including the shrimp consumers. Consumer trust was recognised by several respondents, as one of the key parameters of shrimp industry growth. Respondents were aware that the shrimp consumers are concerned about the news of antibiotics residuals identification in shrimps from Asian countries, and they lack trust in the SSC. Therefore, the respondents stated that BT adoption in ISSC would help gain back consumer confidence and trust with its efficient traceability provision to know the authentic history of shrimp products.

> *"Definitely blockchain will increase trust. I was repeatedly saying the consumer confidence is only the backbone for shrimp farming sector, because unless you have trust in buying certain food safely. Due to trust they start buying product with informed decisions and not just relying on the certifications. (FAR07)*

Some participants highlighted that the enhanced transparency and visibility offered by BT would make it easier for stakeholders, such as exporters, to locate new buyers across new international markets. Few exporters stated the possibility of smoother export inspection processes because of BT by the authorities such as the FDA. More accessibility of information to the authorities would help in reducing the waiting time of containers at ports and decrease rejections of shrimps with hassle-free transport. Thus, this will enable easy access to both new and existing markets for Indian shrimps. As stated by one of the respondents:

> *"I think the transparency offered by blockchain will make it easier to provide all documents more easily to the importing and inspecting authorities such as FDA in the US or similar in the EU and Australia which will give better access to markets for our shrimps." (EX04)*

Regulatory benefits

Respondents noted their perceptions on the regulatory benefits of BT, which focused on government support and regulations, reduction in seafood frauds in the SSC, better food safety and quality, and finally, improved risk and recall management. Interviewees anticipated future regulations on BT from Government or standards requested by processors, traders, or retailers (e.g., more stringent traceability and labelling regulations). The majority of the interviewees responded that the government intervention with new regulations would help the SSC to adopt BT smoothly.

> *"If government interferes to bring everyone together, everyone should do, but again, government is influenced by few big players, but if convinced, the government they can implement this Blockchain for all. (EXP01)*

Some interviewees argued that regulatory benefits would only be seen if it was possible to show a solid benefit to all the parties, and, importantly, the government. However, the government must provide training to stakeholders such as farmers about the use of BT in shrimp businesses for its smoother adoption.

> *"Surely the interference of government will improve like government can give trainings to the farmers to help them to understand the technology well and to connect directly with the companies. In this case, they can get more profits." (PR03)*

Respondents highlighted that enhanced traceability and transparency promised by the BT would provide real-time data on the custody of the shrimp at each stage in the supply chain. Thus, it would be easier to identify the faulty product or fraudulent activities at an early stage or can be traced back to the source smoothly.

> *"Using the technology, you know that whole information about the product is available including the species and caught time and custody of the product. Thus, I think it will be easier to identify any such frauds easily." (EXP04)*

Stakeholders also shared consent on true data availability through BT on food safety and quality of the shrimp, e.g. time of catch/harvest, expiry dates, packaging dates, certifications, etc., perceiving the efficient traceability throughout the SSC.

> *"Yes, blockchain will 100% help because you have a good traceability. The buyer knows when the shrimp was harvested and its origin, so that way see there is no manipulation when you talk about origins, expiry dates, packing dates and all that backed by blockchain." (FAR02)*

Another crucial benefit acknowledged by respondents was the reduced number of recalls due to the accuracy of real-time data collected at the minute level throughout the SSC about the shrimp in each batch, backed with prompt traceability of the product's history. Thus, it was easier to identify the source of the faulty shrimp product.

> *"Correctly identifying the source of information will help in prompt recall management due to real-time information capture at the detailed level of lots and batches would help in identifying damaged lot or product easily." (EXP04)*

4.3.4 Costs

This section presents the outcomes of SSC stakeholders' perceptions and beliefs on the costs required for BT adoption in the sector. These costs include implementation costs and operations costs.

Several stakeholders noted a higher implementation cost required for BT adoption as building any software includes several costs such as development costs, labour training costs, etc. However, many stakeholders noted that all implementation costs will be higher because BT is a new technology and will eventually decrease costs with the time.

> *"Yes, all businesses, they have their own infrastructure, and they have to pay accordingly for their software developments. Any new technology is expensive at start and thus it will have comparatively higher costs involved but eventually it will go down." (EXP04)*

Respondents also mentioned higher training costs as part of the implementation cost. As BT is a new technology, all the stakeholders need to train their employees to use it, which would be a higher cost.

> *"Yes, employee training can increase cost, Programming software installation and all it can increase cost." (PR02)*

Whereas some respondents noted a few other costs involved that includes providing incentives to small scale farmers to motivate them and handhold them to be a part of BT platform.

> *The marketing costs, like showing each stakeholder few advantages and hand holding them through implementation is important initially. So it actually takes the implementation takes more manpower than we think it would. To do anything like he doesn't look at the long-term advantages. We need to give some incentives." (FAR05)*

It was interesting to observe that each stakeholder shared their thoughts on operations costs according to their role in the ISSC. For instance, some farmers highlighted that if BT offers a sustainable model offering increased margins with help transparency and visibility in the market prices, they will accept the higher operations costs.

> *"It might have maybe higher operations costs, but if it is a sustainable model, it involves transparency and getting a better price than minimum support price for farmers, definitely all costs should be taken care, I think." (FAR07)*

Some exporters mentioned the reduction of operational costs with BT adoption as it would reduce the waiting time of containers at the ports, which reduces the insurance and other charges at ports.

> *"It will reduce. Sometimes it is definitely taking out the unwanted things. Just like the container waiting time is reduced, the overall operation costs will be reduced." (EXP01)*

In contrast, some stakeholders denied any change in operational costs, as the costs involved with shrimp handling and transportation would be the same and unaffected with or without BT adoption.

> *"I don't think it will reduce any operations cost because if I have to bring material from one location to another, it doesn't change my cost. My transport doesn't change and my processing cost also doesn't change because its same my boxes my people, my labour, that doesn't change." (EXP03)*

4.4 Discussion

The main aim of this chapter was to explore perceptions, and opinions of ISSC stakeholders on the adoption of BT in the sector. Several interesting results were found. Overall, BT was highly acknowledged by stakeholders to address pain points in existing ISSC operations. It was unexpected to find that the majority of stakeholders positively recognised the costs involved in BT adoption, considering the primary stage of BT development in the sector. This presents an optimistic future for BT's acceptance by stakeholders after considering the ongoing challenges and threats in ISSC. However, for smoother implementation the maximum government support through incentives and trainings for stakeholders especially shrimp farmers would be essential enablers of BT adoption. This study had three objectives. First, to explore in-depth the current challenges affecting SSC in India. Second, to identify and discuss possible solutions related to challenges in the sector, and third, to explore and discuss the benefits and costs of BT adoption in the ISSC.

The results depicted that ISSC faces crucial challenges around quality and food control, management issues in sector, the economic issues that impacts whole sector, information asymetry and technology issues. First, the most commonly highlighted pain point of the industry is the high rate of viral and bacterial diseases in shrimp production, such as white spot syndrome and running mortality syndrome (RMS), which significantly affects financial losses for all stakeholders, especially shrimp farmers. The frequent occurrence of diseases is one of the significant threats to the Indian shrimp sector, as confirmed by (Alavandi et al., 2019; Srinivas et al., 2016; Srinivas & Venkatrayalu, 2016). In addition, the identification of antibiotics in shrimps due to a lack of farmer training and knowledge of good farming practices was another primary concern highlighted by exporters and processors in line with other researchers (Holger et al., 2020; Khan & Lively 2020; Salunke et al., 2020). Furthermore, substantial use of antibiotics by farmers without declaring them, to prevent diseases and boost the growth of shrimp often puts exporters in bad situations, incurring substantial financial losses when shrimp get rejected for this reason. These findings are in line with a few other studies (Khan, 2018; Khan & Lively, 2020) that highlighted the use of antibiotics for the growth of shrimp and post-harvest practices. Coincidently, both these prevalent issues of diseases and the use of antibiotics in ISSC were related to the other challenges identified, such as lack of education among farmers and lack of training, lack of innovative research solutions to these issues, and lack of effective government monitoring on these issues as noted by stakeholders, which is not supported by any other study. However, a majority of stakeholders highlighted that farmers' training is essential to help reduce the diseases issues, which would create awareness among them to buy impact of good quality broodstocks/seeds, which leads to reduced occurrences of diseases, which is seconded by several studies (Holger et al., 2020; Sivaraman et al., 2019; Ulhaq et al., 2022). Stakeholders emphasised that lack of visibility in the SSC leads to a lack of coordination among each other and a lack of trust, which encourages the existing opacity in ISSC. Additionally, this helps the rise of middlemen, which affects the profits of other stakeholders, especially farmers, which is confirmed by other studies (Holger et al., 2020; Motiwala et al., 2021; Prashar et al., 2020). Whereas various stakeholders such as processors and exporters noted concerns about the long waiting for shrimp at foreign ports, which apparently increases the total transportation cost with further reduction in margins as validated by other studies (Vural et al., 2020; Clapano et al., 2022). In addition, an interesting finding on the current challenges was identified about fraud happening in sale of shrimp as BAP/ASC (e.g., Best Aquaculture Practice (BAP) or Aquaculture Stewardship Council (ASC)) certified. At the same time, the whole batch sold is a mix of certified and non-certified shrimp, as noted by one of the stakeholders this happens due to a middlemen collect from massive number of fragmented small size farmers and sale to processors. In addition, there are no accurate records of source of shrimp to trace back. Any study does not second these finding and is one of the critical findings of this study.

Second, in terms of an overall solution to current challenges in ISSC, a common suggestion on using a common shared platform for day-to-day operations for all based on new technologies such as BT was acknowledged by most stakeholders. This would essentially promote good collaborations among all ISSC businesses, for instance offering a direct connection between small unorganised shrimp farmers with the processors and exporters in the SSC, which would reduce their dependency on middlemen and increase their margins, as confirmed by Majdalawieh et al., (2021); Phong et al., (2023); and Tolentino-Zondervan et al., (2022). This would offer complete visibility of operations that enhance transparency and trust among each other significantly. In line with a study by Lidy (2020), who suggested that a fully transparent and traceable supply chain, and good collaboration among stakeholders as a result of end-to-end traceability would be impactful in solving shrimp sector challenges such as finding sources of disease, the use of antibiotics and frauds, and removal of middlemen which increase profit margins for all. It was observed that practical farmers trainings would enhance good farming practices and reduce disease issues, which was in line with other studies (Holger et al., 2020; Srinivas & Venkatrayalu, 2016; Ulhaq et al., 2022).

Third, most stakeholders noted enthusiasm for BT adoption in the sector due to the benefits offered by it. It was observed that stakeholders positively acknowledged both the benefits and costs of BT. The majority of stakeholders highlighted the benefits of BT, which promises end-to-end visibility in the ISSC, resulting in a reduction of overall transaction costs due to access to near real-time authentic data and encouraging better coordination among stakeholders. Several other studies corroborate these findings (Allen et al., 2019; Callinan et al., 2022; Y. Zheng et al., 2023). Moreover, stakeholders such as exporters were keen on being optimistic about finding new market opportunities globally with increased coordination among stakeholders, including the food safety regulatory bodies of importing countries, who would get real-time visibility of authentic data of the shrimps and significantly reduce waiting time on arrival. However, this finding was not seconded by any other study. In addition, the overall transparency in the system would build consumer confidence and trust in Indian shrimps hampered with negative news on identification of antibiotics (Financial Times, 2019; Holger et al., 2020). This finding was in line with Cao et al., (2021) who outlined enhanced consumer trusts due to the integrating self-governance mechanisms of BT.

Furthermore, transparency due to the visibility offered improves profit margins for stakeholders, especially farmers (Niknejad et al., 2021; Ronaghi, 2020;Sugandh et al., 2023). Similarly, the majority of stakeholders noted that enhanced traceability would enable a reduction in frauds or perhaps early detection of them due to real-time data availability while cutting the recall time in food failure. Other studies supported these findings Tanger et al., (2019) on benefits of BT, and Adamashvili et al., (2021) who found that BT can greatly improve food recall management with enhanced traceability and a real-time track record of the food product.

On the contrary, stakeholders recognised that all implementation costs will be higher at the beginning because BT is a new technology and will eventually decrease as it matures and updates with time as in line with some other studies (Bumblauskas et al., 2020; Jabbar & Dani, 2020; Olsen et al., 2019; Venkatesh et al., 2020). However, the operations costs would be increased for the farmers, but farmers showed a consent to rise in operations costs against the benefits offered by BT (Khan et al., 2022). However, to conclude, it was observed that the benefits of BT adoption in ISSC, as per the perceptions and beliefs of the stakeholders, outweighed the costs involved. Therefore, this study highly recommends a BT traceable system for ISSC to address the existing challenges and enhance the demand for Indian shrimps in the domestic and international markets.

4.4.1 Implications for businesses and policymakers

This study provides several relevant implications and recommendations for SSC stakeholders and policymakers in India.

For policymakers:

First, the positive enthusiasm showcased by ISSC stakeholders for BT adoption shows an excellent opportunity for policymakers to converge the whole ISSC on a single BT traceable platform, including from the vast, fragmented unregistered, and unorganised shrimp farm businesses in India to the importers and retailers from importing nations (BCG, 2020; Holger et al., 2020; Sivaraman et al., 2019). This would help efficiently monitor end-to-end operations and quickly identify the issues to resolve.

Second, BT-enabled traceability will assist the government in assigning the correct resources (e.g., cold storage) at the appropriate places and building a structure for the right amount of tax and subsidies for businesses, wherever required, for a good governance framework to address the domestic and international shrimp demand and thus boost the export potential of Indian shrimps.

Third, policymakers must consider building a policy on smooth BT adoption to address the ongoing demand in the sector for BT by incentivising the process and promoting BT benefits for the whole ISSC.

Fourth, policymakers must focus on training and educate stakeholders of ISSC especially, unregistered and unorganised farmers, on good aquaculture practices (Khan, 2018; Xuan, 2021) such as brood stocks, but not limited to, appropriate stocking density, choosing good quality broodstocks for export quality shrimp satisfying the quality shrimp demand from international buyers, handling diseases, removal of antibiotics, and raising awareness of BT knowledge and promoting technology acceptance.

For businesses:

First, from the results, ISSC businesses must recognise the upcoming need of the sector and initiate to adopt an enabled traceability system to build consumer confidence in the credibility of the Indian shrimp. This would help to improve the consumer trust affected by the food safety concerns (Hang et al., 2020; Meera et al., 2023; Peng et al., 2023) due to antibiotics news on Indian shrimp (Gephart et al., 2019), resulting in the rise in demand.

Second, businesses might consider the outcomes of this study to invest in BT and develop an effective way of marketing shrimps, emphasising on providing verifiable, credible information about the origin, production, and handling of their shrimp products accessible to the end consumer through a QR code on the product (Patro et al., 2022; D. Tran et al., 2024). This could assure consumers with valid information on food fraud, food safety, and ethical sourcing.

Third, businesses should note that BT offers better coordination among all stakeholders due to visibility and access to real-time authentic data (Bush et al., 2019; Nascimento et al., 2018; Rocha et al., 2021; Saurabh & Dey, 2020), where all stakeholders would have a direct contact with each other using this BT enabled system which will eliminate their dependency on the middlemen and increase profit margins with further cost reduction (Patel, et al., 2022; Phong et al., 2023; Saurabh & Dey, 2020; Tolentino-Zondervan et al., 2022). Moreover, food safety regulatory bodies of importing countries would also assess the required data including certifications based on the real-time visibility of product flow, which would significantly reduce the waiting time of product on arrival.

4.4.2 Future research directions

Several significant further research possibilities emerged from this study. First, based on the positive enthusiasm among stakeholders to adopt BT in ISSC, there is a need for further detailed research to build a BT adoption framework for ISSC that would be adapted to the existing SSC business model. Second, given the positive enthusiasm from ISSC stakeholders for BT adoption, it is vital to investigate the other end of the supply chain, which is the consumers' behaviours of buying BT traceable shrimps and their willingness to pay (WTP) for these shrimp products. In addition, an assessment of heterogeneity in choices of consumers based on several socio-demographic factors such as age, income, education, buying habits and attitudes would highly recommended. Thus, it will be interesting to compare consumers' acceptance of BT traceable shrimps coupled with the hypothetical scenarios using choice experiments in the top import markets of Indian shrimps, such as the US.

4.5 Conclusion

This study contributes to addressing the current knowledge gap on stakeholders' perception of BT adoption in ISSC, which probes their perception of BT adoption in ISSC, and BT's potential as a solution for existing challenges in ISSC. This is the first empirical study to explore ISSC stakeholders' perceptions of BT adoption. Overall, the results underlined a positive enthusiasm of ISSC stakeholders towards BT adoption in the sector. This positive outlook of stakeholders is a promising sign of the successful integration of BT in the Indian shrimp sector to address existing pain points in ISSC. The stakeholders have recognized the advantages BT, particularly in terms of creating a common transparent platform that fosters better coordination and trust among all stakeholders. BT eliminates the need for intermediaries, enhances traceability, and provides end-to-end transparency, which helps to build consumer trust. It also provides verifiable and reliable information about the origin, production, and handling of shrimp products. However, it was surprising to observe that stakeholders noted positive responses towards both the implementation and operations costs involved in BT implementation, believing the developmental stage of BT in the sector.

CHAPTER 5: Consumer Valuation for Blockchain Traceable Shrimp[10]

This chapter presents a consumer valuation study on BT traceable shrimp products in the United States (US). It investigates consumer preferences for BT traceable shrimp products and their willingness to pay (WTP) while further assessing the consumer characteristics' effect on WTP and exploring preference heterogeneity. It further assesses the effect of consumer characteristics on WTP and explores preference heterogeneity. Additionally, the study tests the impact of different communication messages (highlighting the benefits of BT) on WTP across four treatment groups. Finally, it examines the technology acceptance and readiness of US shrimp consumers for BT.

In addition, this study tests the effect of different communication messages (Benefits of BT) on WTP across four treatment groups. Lastly it examines the technology acceptance and readiness of US shrimp consumers for BT. This chapter is divided into six sections. The first section provides an introduction and motivations of the study, the second section provides a review of existing consumer behavior studies on shrimp, followed by the aims and objectives of the study. The third section describes the materials and methods used to achieve the objectives and answer the research questions. The fourth section presents the results, followed by the fifth and sixth sections which provide discussions of the results and the conclusions, respectively.

[10] A conference paper from this chapter named, '*US Consumer Valuation of Blockchain-Certified Traceability for Shrimp: Does Information Matter?*' has been accepted for a Lightning Session at the 2024 AAEA Annual Meeting in New Orleans, LA, July 28-30, 2024.

5.1 Introduction

The global seafood industry has complex and opaque supply chains with multiple stakeholders from farm/bait to fork (Rahman et al., 2021). In spite that seafood is one of the top traded food commodities globally, it is highly vulnerable to illegal, unreported, and unregulated (IUU) frauds which includes mislabelling, and species substitution (Cawthorn et al., 2018; Gordoa et al., 2017; Mathisen et al., 2018). Considering recent food safety incidents and recalls, there are concerns that the current seafood supply chains are not efficiently equipped to easily identify the source of contamination (Coronado-Mondragon, 2020; Khan & Lively, 2020). Among them, shrimp is the world's largest traded and consumed seafood accounting for approximately 15% of global seafood sales (FAO, 2022). Thus with the increasing demand for seafood globally of which shrimp is the favourite, there is a growing demand from consumers for transparency about the geographical origin of the fish product, where and when it was captured or raised, who captured or raised it, under what conditions it was stored, under what conditions it was transported, what process of transformation it suffered and in what conditions, etc. (Hoque et al., 2022; Fox et al., 2018; Howson, 2020).

5.1.1 Motivation behind studying US shrimp consumer on BT

Shrimp is one of the most popular seafood both economically and culturally in the US household diets being a rich source of protein (Gopi et al., 2019; Holger et al., 2020; Xuan, 2021). In the US an average annual consumption of shrimp has risen to 5.9 pounds per capita (SeafoodSource, 2024). However, it is seen that currently, US cannot sustainably produce (i.e. production of seafood without depleting the source with harm to the environment) seafood to fulfil the rising demand by the consumers through both fisheries and aquaculture industry, and thus have to rely on the increasing imports which often raise food safety concerns (Ferreira et al., 2022). US shrimp imports in 2023 were 785,837 MT (by volume), and valued at USD 25.3 billion with

India being the top exporter with 22,842 MT followed by Ecuador with 17,539 MT (SeafoodSource, 2024). However, food safety concerns continue for shrimps coming from these countries resulting in the rejection of shrimp containers due to the identification of the residues of banned antibiotics (FDA, 2022). However, remarkably only 2% of containers are checked and verified by the FDA which increases the possibility of these shrimps reaching the end consumers (Khan & Lively, 2020). Such shrimp could pose serious food safety concerns for human health (Okocha, et al., 2018) and have affected consumers' perception and their buying behaviors of shrimps, considering the food safety and quality concerns (Khan & Lively, 2020).

Reports of fish mislabelling fraud (), detection of contaminated seafood, and the use of banned antibiotics in shrimp have all contributed to a decline in consumer trust in the seafood industry as a whole (TheGuardian, 2021 ,SeafoodSource, 2024; Ndraha et al., 2018; News21,2011).

(Asche & Bronnmann, 2017)(Hoque et al., 2022) Conversely, it is estimated that in the US around 260,000 people fall sick each year due to consumption of contaminated fish which majorly includes crustacean shellfish such as shrimp, which is the most consumed seafood in the US (CDC, 2022; White et al., 2021). Therefore, such events have further hampered consumer confidence in the current seafood supply chains which lack transparency and swift recall management and are vulnerable to several frauds (Mccallum et al., 2022; Rahman et al., 2021). Thus, US consumers are demanding assurance of seafood safety and quality in terms of freshness, and reliability of sustainable labels on products to make informed decisions when buying seafood (Hoque et al., 2022;Fox et al., 2018; Howson, 2020). Moreover, the lack of end-to-end traceability in the SSC makes it impossible to identify and verify the source of issues such as antibiotic use (Love et al., 2021). This exposes the vulnerability of SSC to severe health and safety issues for consumers (Asche et al., 2022). Current SSC stakeholders (such as hatcheries, feed suppliers, farmers, processors, exporters, distributors, and retailers) conduct their quality checks and maintain their records of transactions (majorly paper-based), thus promoting non-transparent and hence a lack of robust traceability system throughout (Stirton, 2020). Therefore, such opaque supply chains make it difficult for rapid identification of food safety incidents and respond quickly (Oliveira et al., 2021; Olsen et al., 2019).

In contrast, emerging innovative technologies such as BT promise to address these challenges by offering efficient end-to-end traceability of shrimp products with added security to the data captured and resist entry of any fraudulent data in the system (Blaha & Katafono, 2020; Garrard & Fielke, 2020; Tolentino-Zondervan et al., 2022). BT would thus make the SSCs more transparent and visible through a shared, distributed, and secure system viewable by the public (Blohmke, *et al.*, 2019; Gopi *et al.*, 2019). BT would enable end consumers to view the product history such as the origin of shrimp, how it was raised (*in case of farm-raised*), or caught with the timestamps of the activities including the origin country and sustainability standards throughout the journey to the store. Consequently, BT promises to strengthen and concrete consumer trust and confidence in overall SSC with enhanced traceability and transparency for US consumers (Blaha & Katafono, 2020; Cook, 2018). For shrimp businesses/stakeholders BT promises access to real-time data availability applicable to plan business operations efficiently with the smoother paperless transaction through smart contract (Hang et al., 2020; Meera et al., 2023; Tolentino-Zondervan et al., 2022). As a result this will generate more market opportunities for shrimp businesses (Olsen, *et al*., 2019; Pan *et al.*, 2019; Kumar, Liu, and Shan, 2020; Callinan *et al.*, 2022). Moreover, BT would enhance the quality of data, and smooth monitoring of safety procedures for compliance purposes to be shared with import authorities, and the end consumers (Callinan et al., 2022; Olsen et al., 2022). In addition, in case of food recalls BT provides a real-time trace-back mechanism with prompt identification of the source of contamination (Olsen et al., 2019; Prashar et al., 2020; Wang, Han, et al., 2019). Thus, this promises the required transparent visibility, and efficient traceability in the SSC making it crucial to understand the potential benefits of BT adoption in SSC as a possible option for improving supply chain distribution systems (Bechtsis et al., 2019).

5.1.2 Consumer Attitudes in Blockchain Adoption

Attitudes are crucial in consumer decision-making, especially when it comes to adopting new technologies like BT-enabled food traceability systems (Contini et al., 2023). In this study, attitudes are defined as an individual's positive or negative evaluation of BT-based traceability in shrimp supply chains. This concept is separate from other factors such as perceived transparency, trust, security, and willingness to pay (WTP), which either influence attitudes or result from them. The study incorporates attitudes based on established behavioral theories, specifically the Theory of Planned Behavior (TPB) by Ajzen (1991) and the Technology Acceptance Model (TAM) by Davis (1989), both of which indicate that attitudes greatly impact consumer behavior and adoption intentions. For instance: Perceived transparency and trust are not attitudes but rather cognitive evaluations that shape attitudes toward BT adoption (Gefen et al., 2003). Perceived usefulness and ease of use are antecedents of attitude formation, as conceptualized in the Technology Acceptance Model (Davis et al., 1989). Willingness to pay (WTP) and purchase intention reflect behavioral outcomes influenced by attitudes, rather than attitudes themselves (Fishbein & Ajzen, 1975). Thus, the variables used in Table 10 (Section-5.4.3) categorize variables based on their role in shaping BT adoption. The refined framework distinguishes between: 1) Attitudinal variables, which represent consumers' evaluations of transparency, trust, and BT usability; 2) Antecedent variables, which include beliefs about food supply chains, perceived transparency, and food values that shape consumer attitudes, and 3) Behavioral outcome variables, which reflect consumer decisions regarding BT adoption, willingness to pay, and acceptance of digital traceability labels.

Attitudinal variables:

One of the key attitudinal variables is attitudes toward transparency in food supply chains, which reflect how consumers value access to clear, verifiable information about the origin and journey of food products. Transparency is particularly important in the case of credence goods such as shrimp, where consumers cannot directly verify attributes like sustainability and sourcing. Studies indicate that consumers with strong transparency concerns are more likely to develop favourable attitudes toward BT-based traceability, as it enhances supply chain visibility and reduces information asymmetry (Jiang et al., 2023; Acciarini et al., 2023). Empirical evidence also suggests that when transparency is perceived as valuable, consumers are more willing to engage with digital verification technologies, thereby increasing BT acceptance (Yang et al., 2024).

Similarly, attitudes toward trust in the food supply chain influence consumer perceptions of BT as a mechanism for improving accountability and product credibility. Trust is a key determinant of consumer confidence in food safety and traceability systems, shaping how consumers evaluate the reliability of BT-enabled labels (Vázquez Meléndez et al., 2024). Studies indicate that consumers who distrust conventional food supply chains due to concerns about fraud, mislabeling, or regulatory failures are more likely to develop positive attitudes toward BT adoption, seeing it as a corrective mechanism that enhances traceability (Shew et al., 2021; Rao et al., 2023). Trust also plays a crucial role in technology adoption, particularly in high-risk food categories like seafood, where authenticity and sourcing information are key decision-making factors (Lin et al., 2021).

Another important factor is technology readiness (TRI) and BT adoption attitudes, which determine consumers' willingness to engage with BT-based transparency solutions. Technology readiness reflects an individual's optimism, innovativeness, discomfort, and insecurity toward digital technologies (Parasuraman, 2000). Consumers with high technology readiness are more likely to adopt BT traceability tools, recognizing their advantages in data security and verifiability (Wang & Scrimgeour, 2023). Conversely, individuals with low TRI scores may perceive BT as too complex or unfamiliar, limiting adoption (Knauer & Mann, 2020). These findings emphasize the importance of designing user-friendly BT interfaces to enhance consumer confidence and encourage wider engagement with digital traceability solutions (Duong et al., 2024).

Antecedents of Attitudes Toward Blockchain Adoption

Attitudes toward BT-enabled traceability are shaped by consumers' beliefs and perceptions regarding transparency, trust, and food values. This study includes several antecedent variables (Table 10), which influence how consumers evaluate BT, aligning with the behavioral frameworks of TAM and TRI models (Davis, 1989; Parasuraman, 2000).

One of the primary antecedents is the belief in transparency as a necessary attribute of food supply chains. Consumers differ in their perceptions of whether transparency is essential for ensuring food safety, authenticity, and sustainability. Those with stronger transparency concerns are more likely to develop favorable attitudes toward BT adoption, as it provides verifiable data that aligns with their traceability expectations (Jiang et al., 2023; Duong et al., 2024). Research indicates that when transparency is seen as a key decision-making factor, BT-based labels are perceived as more credible and valuable (Sepe, 2024; Acciarini et al., 2023). Another key antecedent is the belief that the food supply chain is already trustworthy. If consumers trust existing regulatory systems and food labels, they may see little need for BT-based verification, perceiving it as redundant (Contini et al., 2023). In contrast, consumers with low trust in conventional food systems tend to exhibit stronger attitudes toward blockchain adoption, as they view BT as a way to address traceability gaps and prevent fraud (Jiang et al., 2023; Yang et al., 2024). These diverging trust perceptions suggest that BT adoption may be more successful in markets where food fraud concerns are prevalent, such as seafood and organic food industries (Rao et al., 2023).

Additionally, perceptions of food values such as safety, taste, price, and nutrition also shape attitudes toward blockchain traceability. Consumers who prioritize food safety tend to favor blockchain verification, seeing it as a tool for risk reduction and contamination prevention (Shew et al., 2021; Acciarini et al., 2023). In contrast, price-sensitive consumers may perceive blockchain as an unnecessary cost driver, unless its transparency benefits outweigh cost concerns (Yang et al., 2024). These findings suggest that blockchain adoption efforts should focus on communicating its added value, particularly in relation to food safety and sustainability claims (Vázquez Meléndez et al., 2024).

Behavioral Outcomes of Attitudes

The relationship between consumer attitudes and blockchain adoption is reflected in behavioral outcome variables, which capture how positive or negative attitudes toward blockchain influence real-world purchasing decisions. Table 10 includes behavioral indicators such as knowledge and awareness of blockchain technology, willingness to pay (WTP) for blockchain-enabled transparency, and acceptance of blockchain-based traceability labels.

Knowledge and awareness of BT play a crucial role in adoption behavior. Consumers who are already familiar with blockchain principles such as decentralization, immutability, and transparency are more likely to trust and accept BT-based traceability systems (Rao et al., 2023; Jiang et al., 2023). However, limited BT knowledge can lead to skepticism, particularly among consumers who associate BT with cryptocurrency rather than food traceability (Shew et al., 2021). Addressing this knowledge gap through educational initiatives can improve consumer confidence in BT-labeled food products (Acciarini et al., 2023).

Willingness to pay (WTP) for BT-verified shrimp is another key behavioral outcome. Research shows that consumers with favorable BT attitudes are more likely to pay a premium for products with verified traceability, particularly when food safety and sustainability are top concerns (Duong et al., 2024; Yang et al., 2024). In contrast, cost-conscious consumers may be reluctant to adopt blockchain-traced products unless they perceive a direct benefit (Vázquez Meléndez et al., 2024).

Lastly, acceptance of BT-based traceability labels is directly influenced by consumer attitudes. Consumers who trust BT's transparency and security features exhibit higher acceptance of QR-code-based labeling systems, integrating blockchain-traced products into their purchasing habits (Sepe, 2024; Acciarini et al., 2023). Studies indicate that BT-labeled products enhance brand credibility and consumer loyalty, reinforcing the role of trust in adoption behavior (Wang & Scrimgeour, 2023).

5.2 Background: Consumer preferences for shrimps

The current literature provided valuable insights into consumer preferences and WTP for shrimp products, reflecting a growing interest in sustainable and certified seafood choices across various consumer markets. Existing studies underscore increasing consumer acceptance of various labels on shrimp product, including eco-labels, sustainability labels, organic labels, and no-antibiotics labels, over unlabelled products, signalling a growing consumer interest and higher WTP for labelled shrimp products. Researchers like Phong et al., (2023) investigated consumer valuation in Vietnam, revealing a preference for sustainability-labelled shrimp over conventional farmed varieties lacking such labels. Similarly, Aya et al., (2021) highlighted the higher perceived value of eco-labelled white shrimp among Vietnamese consumers compared to unlabelled options.

This trend is further supported by Xuan (2021) study, which identified a significant premium WTP by Vietnamese consumers on farmed shrimp carrying the Aquaculture Stewardship Council (ASC) logo, underscoring the influence of third-party certifications on consumer behavior. Similarly, regarding Chinese consumer preferences, Yin et al., (2022) emphasized a heightened WTP for shrimp bearing organic certification and traceability information, echoing findings from Yin et al., (2020) who observed a similar pattern of increased WTP for organically labelled and traceable white shrimp among urban Chinese consumers. Notably, there appears to be a differentiation in premium pricing, with consumers willing to pay more for European Union (EU) organic-certified shrimp compared to domestically certified counterparts.

This trend is further supported by Xuan (2021) study, which identified a significant premium WTP by Vietnamese consumers on farmed shrimp carrying the Aquaculture Stewardship Council (ASC) logo, underscoring the influence of third-party certifications on consumer behavior.

In a distinct context, studies in Denmark by Hukom et al., (2020) revealed nuanced preferences for warm-water versus cold-water shrimp, with consumers demonstrating a higher WTP (40.07%) for fresh warm-water shrimp over frozen counterparts. Conversely, this market segment preferred frozen cold-water shrimp over fresh options.

Further insights from the United States, as explored by Soley (2016), demonstrated preferences among American consumers for shrimp products sourced from Community-Supported Fisheries (e.g., Homegrown by Heroes), emphasizing the appeal of locally supported seafood initiatives. Additionally, the MSC label was identified as a significant driver of consumer utility and preference across states. Ortega et al., (2015) in their US-based study, they investigated the impact of news headlines on consumer preferences using choice experiments, highlighting that exposure to food safety headlines, particularly concerning products from China and Thailand, significantly influenced consumer preferences and WTP. In contrast, another study in the US by Wang and Widmar (2014), identified that consumers exhibited the highest WTP for enhanced food safety attributes, followed by preferences for products with no antibiotic use and environmentally friendly production methods. Furthermore, Roheim, et. al, (2012) conducted choice experiments with consumers from Rhode Island, revealing a preference for wild-caught shrimp over farmed options, even when the latter were certified. This preference was largely driven by freshness considerations, emphasizing the importance of product attributes beyond certification status in consumer decision-making.

Similarly, Oishi et al., (2010) investigated the potential demand of Japanese consumers for eco-labelled shrimps using Conjoint analysis. Their findings demonstrated positive consumer preferences for products certified as 'domestic' or bearing eco-labels. Notably, Japanese consumers exhibited the highest WTP for domestic products, followed by eco-labeled products, with consumers also showing willingness to pay premium prices for Marine Stewardship Council (MSC)-certified products. In the US context, Wirth, et. al, (2007)conducted a Conjoint analysis with shrimp consumers, highlighting the positive impact of credence features such as country-of-origin labels on product utility. Consumers attributed higher positive utility to country-of-origin labels compared to other shrimp attributes. Additionally, consumer utility weight for wild-harvested shrimp was slightly higher than for farm-raised shrimp.

Despite widespread concerns over food safety issues and fraud, particularly in the seafood sector, the current literature reveals significant gaps in evidence-based studies on shrimp, particularly related to consumer valuation of BT traceable shrimp, especially within the top shrimp import market globally, the US.

This study aims to address these gaps by investigating US shrimp consumers' valuation of BT traceable products and their WTP. The findings will provide valuable guidance for researchers, businesses, and policymakers to consider the adoption of BT in the SSC and the launch of BT traceable shrimp products in the US market, aligning with rising consumer demand for transparent and certified seafood options (Ding et al., 2022; D. Tran et al., 2024).

The study's specific aim and objectives are outlined below, aiming to contribute to the existing literature and support informed decision-making in the context of sustainable seafood consumption and supply chain management.

5.2.1 Aim and objectives

This study aims to investigate US consumers' valuation of BT traceable shrimp. It has the following four objectives, (i) to investigate the consumer preferences and WTP for BT traceable shrimps (ii) to study the effect of consumer characteristics (i.e. socio-demographics, purchase habits, and attitudes) on preference heterogeneity in WTP (iii) to explore how communication messages effect WTP for BT traceable shrimps; and (iv) to test how consumers' technology readiness and acceptance of the new technology can influence WTP for BT traceable shrimps.

5.3 Materials & methods

5.3.1 Choice experiment design

This study uses a discrete choice experiment (DCE), which is one of the most widespread techniques to examine the consumer WTP (willingness to pay) for goods (McFadden, 1974). This DCE study uses four attributes to describe different shrimp products, viz.-Blockchain certification label, QR-code label, Antibiotic label (e.g., No antibiotic label), and the price with each different level. These attributes were determined from the extant literature review (See Chapter 2) and used to fill the research gap in consumer studies on shrimp and technology adoption. Table 6 presents the attributes and levels used in the study and the description of labels used for the attributes. Firstly, as this study aims to investigate consumer's WTP for BT traceable shrimp, the label BT is included. First, two levels of BT label were specified: (i) Blockchain certified label and (ii) No label provided. Secondly, we used two levels of QR code as the use of QR code is combined with BT used to trace the history of products. Therefore, we used (i) QR code and (ii) no QR code provided. Third, we included antibiotics labels given that antibiotics possibly would have been used during shrimp production. Thus, the two levels of antibiotics were used i) use of the 'No antibiotics ever' label and ii) no label provided. Lastly, four price levels were specified based partly on the existing market prices for shrimps ($ 6.00/lb, $10.00/lb, $14.00/lb, $18.00/lb)[11] during the study design.

Table 6-Labels, attributes, and levels description

Attribute labels	Attribute description	Levels
Blockchain Certified	The presence of this label indicates that independent parties (shrimp farmers/producers, processors, traders, exporters, certification agencies, and retailers) are sharing blockchain technology to verify the source, quality, and other attributes of the shrimp.	0- No Label 1-Blockchain Certified Label
	This image is known as a QR code. It can be easily scanned by compatible mobile devices to view a particular website on the internet. This particular QR code indicates that you can immediately view information regarding the shrimp product on a smartphone or other device (provided there is a connection to the Internet).	0- Code Absent 1- Code Present
NO ANTIBIOTICS EVER	The presence of this label indicates that no antibiotics were ever used in the production of shrimp	0- No label 1- No antibiotics ever

[11] The prices for shrimp were based on prices recorded in different retail stores in the United States of America approximately reflecting the market price for a pound of jumbo shrimp during the time of study, which is a commonly consumed shrimp in the US with 15-25 counts (LobsterAnywhere, 2022).

Price ($)		0- $ 6.00 /lb (USD) 1- $ 10.00 /lb (USD) 2- $ 14.00 /lb (USD) 3- $ 18.00 /lb (USD)

The selected attributes and their levels were then used to generate an orthogonal fractional factorial design, which was optimized for D-efficiency (97.21%) using Ngene 1.2.1 (ChoiceMetrics, 2018). Preliminary data (i.e. a pilot study) was collected from a small number of consumers (i.e. 80) which was not selected for the final study. The design resulted in the creation of 8 choice sets, each comprised of two product alternatives (options A and B) and an "opt-out" option (option C) (see an example in Figure 13). The choice tasks were presented in a random order to the respondents. The respondents were provided with a clear explanation and description of the study attributes and levels. Before facing the choice sets, participants received the instructions to imagine themselves shopping in a retail store, and they were instructed on how to complete the DCE. A cheap talk (CT) script was added to mitigate hypothetical bias (Cummings et al., 1999) (see Appendix G for the CT script).

Furthermore, to achieve the second objective of the study, on completion of the choice tasks, the respondents were asked to answer a questionnaire to collect information on their socio-demographics, habits, and attitudes toward food as in line with other studies (Asioli et al., 2016; Birch & Lawley, 2013; Nguyen et al., 2015; Monterrosa et al., 2020). Specifically, we included questions about sociodemographic characteristics (e.g., gender, income, age, education), shrimp purchasing habits (Spence et al., 2018), awareness about BT, food values (Lusk & Briggeman, 2009), attitudes towards trust and transparency in the food supply chain were explored (Pozelli et al. al., 2022; Robinson et al., 2020)(See section 5.4.3). To achieve the third objective, we used four DCE treatments to test the effect of different communication messages on WTP, as described in detail in section 5.4.4. Moreover, to achieve the fourth and last objective of this study to investigate the consumer's attitudes on acceptance and readiness of BT, we adapted a model called TRAM (See section 5.4.5) based on the technology acceptance model (TAM) and technology readiness index (TRI). As suggested by the authors, the appropriate scales were used in the main questionnaire (Please see Appendix I).

(Created by author)

Figure 13-Sample CE task with all attributes.

5.3.2 Data

The data was collected from an online, stated-preference survey conducted during June 2023, with 866 consumers from the US with a market research agency platform, Bilendi (Bilendi UK), using sampling quotas that required equal age, gender and income groupings in line with US national census statistics. The questionnaire was designed on Qualtrics LLC, Provo (USA) (Appendix G) for participants recruitment based on sampling quotas in terms of age (21 % between 18-29, 17 % between 30-39, 16 % between 40-49, 17 % between 50-59 and 29% 60+ years old), gender (50 % males and 50 % females), and gross income (30% with <$30k,36% in between \$40k-\$99.99k, and 34% for \$100k or more) which is similar to the census population (United States Census Bureau, 2021). Consumers who were at least 18 years old and primarily or more than half times responsible for household food purchases were included in the study. Additionally, consumers who never buy or buy shrimp less than every six months were excluded from the study. Informed consent was taken from all respondents in the study, and an ethical clearance board approved our study at the University of Reading. In order to ensure data quality, we used' attention check' questions as designed by Meade and Craig (2012) to stimulate respondents to pay extra attention to the succeeding questions (it is not used to detect dishonest replies). Thus, firstly, prior to presenting the series of choice tasks, respondents were asked whether they had 'devoted (their) full attention to the questions so far' and whether, in their honest opinion, they believed that we should use their responses for the study (see questionnaire in Appendix D). This question was strategically placed before the most critical questions, such as the choice tasks. Secondly, only respondents who took more than one-third of the median time duration to complete the survey were included in the study.

Justification of Sample Representativeness in the Choice Modelling Exercise

The representativeness of the sample for the U.S. shrimp consumer population was ensured through quota-based sampling, where key demographic variables such as age, gender, and income were aligned with U.S. Census Bureau (2021) data. Bilendi ensured that the sample distribution closely resembled the broader U.S. consumer population. To evaluate representativeness, the sample's demographic composition was compared with publicly available data from the United States Census Bureau (2021). The sampling quotas used in data collection were explicitly designed to reflect key socio-demographic characteristics of the U.S. population, ensuring that the sample was not biased toward specific consumer segments.

Representativeness of Shrimp Consumers in the U.S.

Since this study focuses on shrimp consumers, it was essential to ensure that the sample also reflected real-world seafood consumption patterns. According to the National Fisheries Institute (2021), shrimp is the most consumed seafood in the U.S., with over 70% of seafood consumers reporting shrimp consumption at least once a month. The sample used in this study focused exclusively on shrimp consumers, ensuring that the respondents represent the actual consumer base relevant to blockchain-enabled shrimp traceability.

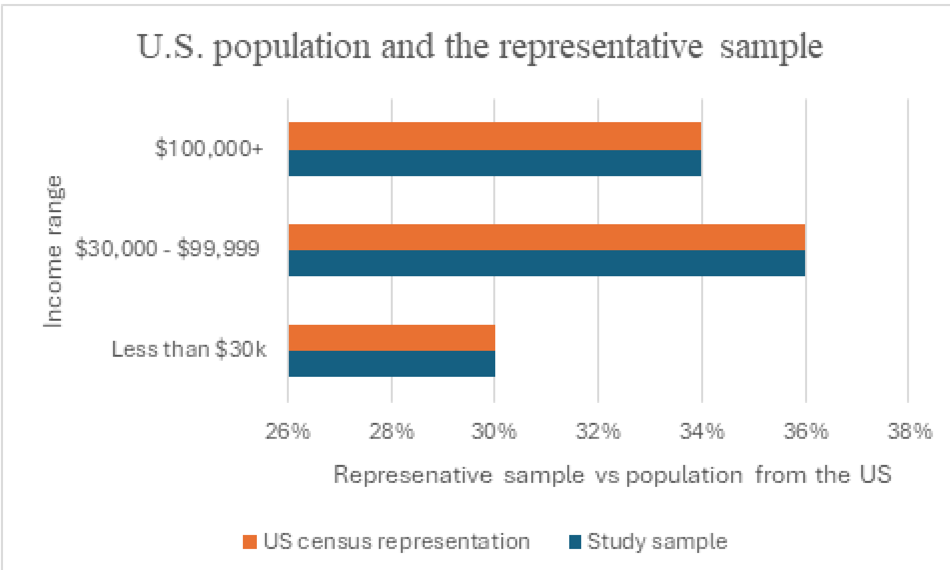


Figure 14-Sample representative to the target population (Income).

Furthermore, demographic trends in U.S. seafood consumption suggest that older populations (50+ years) tend to consume more seafood, a pattern that is well-represented in the sample, given the 29% representation of respondents aged 60+ years (NOAA, 2022). This ensures that the study captures preferences from the most active shrimp consumer segments.

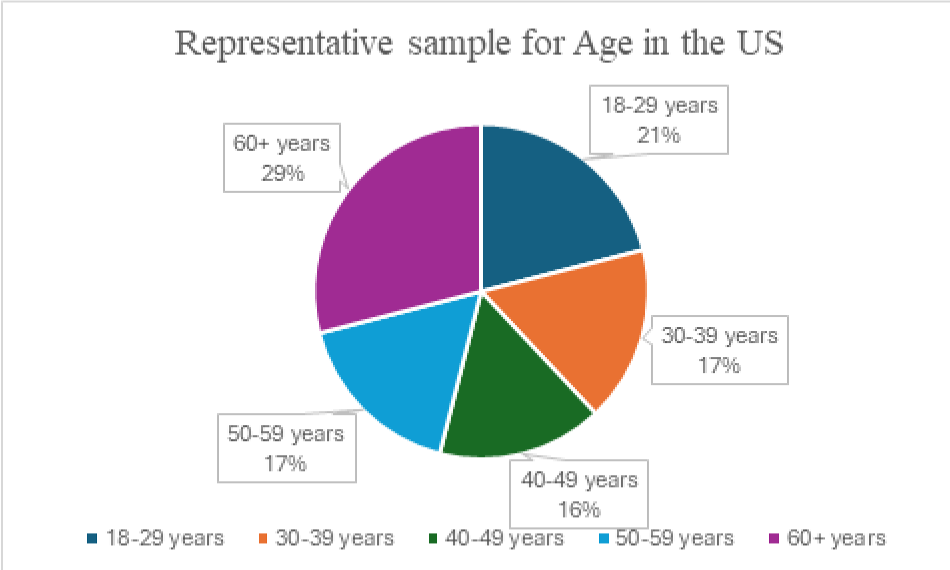


Figure 15 -Sample representative to the target population (Age).

Justification for Target Population Choice: Nationwide vs. State-Level Sampling

The choice to sample participants from across the entire United States, rather than limiting the sample to states with high shrimp consumption, was intended to capture a more diverse range of consumer attitudes toward BT-enabled shrimp supply chains. States such as Louisiana, Texas, and Florida are known for higher shrimp consumption, which is influenced by local culinary traditions and cultural preferences; however, a nationwide sample offers broader insights that can reveal general consumer trends across varied demographic groups in the U.S. (Snyder et al., 2016). Taking a national approach enables this study to assess consumer attitudes toward blockchain's role in seafood traceability on a larger scale, beyond traditional shrimp-consuming areas.

5.3.3 Econometric models

A broader, nationwide sample also allows for a better understanding of how different segments of the population, including those in regions with lower seafood familiarity, perceive the transparency and traceability benefits of blockchain technology. This approach aligns with previous studies on technology adoption, where sampling a broader population helps reveal trends applicable across various geographic and demographic segments, which can provide valuable insights for stakeholders involved in national-level supply chains (Rogers, 2003). Additionally, including states with both high and low shrimp consumption enables comparative analysis, potentially highlighting regional differences in consumer attitudes and enhancing the study's ability to generalize findings to the larger U.S. market (Aizaki, et al., 2014).

The data captured was estimated using discrete choice modelling (DCM) as outlined by (Train, 2009), which is typically used to analyse choice data and is consistent with the attribute-based choice method based on the Lancaster Consumer Theory (Lancaster, 1966) and Random Utility Theory (RUT) (McFadden, 1974), which describes the utility U of an individual n of choosing alternative j in choice situation t can be represented as:

$$U_{njt} = \beta\, x_{njt} + \varepsilon_{njt} \tag{1}$$

Where, where x_{njt} is a vector of the observed variables linking to an individual *n* of choosing alternative *j* in choice situation *t*; β is a vector of the significance of the attributes (x) representing the respondent's marginal utility associated to the attributes; and ε_{njt} is the unobserved error term, which is assumed to be independent of the vectors β and x.

This study uses mixed logit model (MXL) with specification of the utility function in the WTP space, which gives direct estimates of WTP terms in form of currency value (i.e. $USD in this case) (McFadden & Train, 2000). MXL in the WTP space is proven to be more practical, which also provides a realistic distribution of WTP (Bliemer & Rose, 2013). Thus, in a WTP space approach, the coefficients can directly be interpreted as WTP (monetary value) since the utility is parameterised (McFadden & Train, 2000; Scarpa et al., 2008), and so are the standard errors that need not be derived using simulation (Poe et al., 2005) or closed-form approximations such as via the delta method (Bliemer & Rose, 2013). Thus, MXL (WTP space) model results are used for this study, as this model is specifically designed to estimate the monetary value (WTP) that individuals assign to various attributes or levels in the choice experiment, which allows the researcher to quantify the economic value participants place on different attributes (Hensher & Greene, 2003). The MXL model in the WTP space was estimated using the Stata module *mixlogitwtp* (Hole, 2007). All the models were estimated using Stata/SE 18.0 software (Stata-Corp LP, College Station, USA, 2021).

We analysed the data in three steps. First, we studied consumers' WTP for shrimp, considering design attributes for main effects only. The empirical specifications of the utility levels at the attributes of each choice for main effects were formulated as follows:

$$U_{njt} = \alpha_n \,(ASC - PRICE_{njt} + \theta_{n1}\, BT_{njt} + \theta_{n2}\, QR_{njt} + \theta_{n3}\, ANTIBIO_{njt}) + \epsilon_{njt} \qquad (2)$$

Where n represents the individual, j stands for each of the three alternatives available in the choice set, and t is the number of choice occasions, and α_n is the price scale parameter that is assumed to be random, and to follow a log-normal distribution. Since price effects usually influence choices in a single direction (often negatively), a log-normal distribution is ideal as it guarantees non-negative values, effectively capturing the range of variability in how price impacts choices. Whereas other parameters followed normal distribution to the BT, QR and ANTIBIO labels that enable symmetrical variation around the mean, capturing potential variability in consumer responses, from strong preferences to neutral or less concerned perspectives for these labelled products. The ASC is the alternative constant indicating the selection of the opt-out option. The price ($PRICE_{njt}$) attribute is represented by four experimentally defined price levels (i.e. $ 6.00 /lb (USD), $ 10.00 /lb (USD), $ 14.00 /lb (USD), and $ 18.00 /lb (USD)). BT_{njt} is a dummy variable for the use of blockchain label, taking the value of 1 if the label is present and 0 if no information is presented, QR_{njt} is a dummy variable for the use of QR code, taking the value of 1 if the code is present and 0 if no information presented, and $ANTIBIO_{njt}$ is a dummy variable for use of antibiotic label taking the value of 1 if the 'No antibiotics ever' label is presented and 0 if no information is presented. Whereas θ_{n1}, θ_{n2} and θ_{n3} are the coefficients of the estimated WTP values for the BT label, the QR code, and the 'No antibiotics ever' label, respectively. $\in_{njt}$ is an unobserved random term that is distributed following an extreme value type I (Gumbel) distribution, independent and identically distributed (i.i.d.) over alternatives. The parameters corresponding to the three non-price attributes were modelled as random parameters assumed to follow a normal distribution, while the opt-out parameter was modelled as a fixed parameter (McFadden & Train, 2000).

Second, we investigated consumers' WTP for shrimp, considering the design attributes' main effects and the interactions among attributes to test the effect on WTP. Thus, based on the eq. (2), the utility MXL model for shrimp *j*, for individual *n*, in choice occasion *t* can be derived as:

$$U_{njt} = \alpha_n (ASC - PRICE_{njt} + \theta_{n1} BT_{njt} + \theta_{n2} QR_{njt} + \theta_{n3} ANTIBIO_{njt} + \theta_{n4} BT_{jt} \times QR_n + \theta_{n5} BT_{jt} \times ANTIBIO_n + \theta_{n6} BT_{jt} \times PR_n) + \in_{njt} \quad (3)$$

Where in addition to eq. 2, attributes from interaction terms such as $BT_{jt} \times QR_n$ is an interaction term between QR code and BT label showcasing how the change in effect of BT label on utility changes with both levels of QR. Similarly, $(ANTI \times BT)_{njt}$ is an interaction term between No antibiotics label and BT label showcasing how the change in effect of BT label on utility changes with both levels of No antibiotics label. Whereas, $(PR \times BT)_{njt}$ is an interaction term between price levels and BT label showcasing how the change in effect of BT on utility changes with all four levels of price.

Third, we examined the effects of various consumer characteristics on consumers' WTP for shrimp considering the design attribute 'Blockchain' main effects plus the interactions with the treatments and several consumer characteristics with the attribute BT to test whether consumer

WTP for shrimp is affected by those characteristics. As such, the specification of the utility (U) function in our study can be defined as follows:

$$U_{njt} = \alpha_n (ASC - PRICE_{njt} + \theta_{n1} BT_{njt} + \theta_{n2} QR_{njt} + \theta_{n3} ANTIBIO_{njt} + \theta_{n4} BT_{jt} \times GENDER_n + \theta_{n5} BT_{jt} \times AGE_n + \theta_{n6} BT_{jt} \times INCOME_n + \theta_{n7} BT_{jt} \times EDUCATION_n + \theta_{n8} BT_{jt} \times HEARING_n + \theta_{n9} BT_{jt} \times TRUST_n + \theta_{n10} BT_{jt} \times TRANSPERANCY_n) + \epsilon_{njt} \quad (4)$$

Where θ_4, θ_5, θ_6, θ_7, θ_8, θ_9, and θ_{10} are the coefficients of the interaction terms between the attribute BT and the respective consumer characteristics. Specifically, GENDER is a dummy variable representing the gender of the consumer, taking the value of 0 for females and 1 for males. AGE is a continuous variable representing the age of the respondent in years. EDUCATION is an ordinal variable representing the education level of the consumer, taking the value of 1 for Elementary/ High school, 2 for High school diploma, 3 for some college qualification, 4 for technical school diploma, 5 for associate degree, 6 for bachelor’s degree, 7 for master’s degree, 8 for doctorate degree, and 9 for any other. INCOME is a categorical variable representing the income of the consumers, taking the value of 0 for <$40k, 1 for $40k-$99.99k, and 2 for $100k. HEARING is a dummy variable representing whether the consumer has heard the term ‘blockchain’ prior to the study, taking the value of 1 if the consumer has heard this term else 0 for not heard before. TRUST is a dummy variable representing whether the consumer has trust on the current food supply chain as the term ‘TRUST’, taking the value of 1 if the consumer has trust on the current food supply chain else 0 for no trust. Similarly, TRANSP is a dummy variable representing whether the consumer believes that the current food supply chain is transparent, taking the value of 1 if the consumer believes on transparency in the food supply chain else 0 for no believe.

The rest of the variables are specified as in Eq. (3). The parameters corresponding to the three non-price attributes were modelled as random parameters assumed to follow a normal distribution. In contrast, the opt-out and the interactions of BT with consumer characteristics (i.e. GENDER, AGE, EDUCATION, INCOME, HEARING, TRUST, TRANSPARENCY) parameters were modelled as fixed parameters. Based on Akaike information criterion (AIC) and Bayesian information criterion (BIC) parameters, the appropriate model was selected as fit for the test.

5.3.4 DCE treatment groups

To achieve the third objective, this study used four DCE treatments to test the effect of different communication messages on consumer WTP. The participants were assigned to one of four groups before taking part in a Discrete Choice Experiment (DCE). Each group was presented with a specific communication message, which was developed based on themes identified in a literature review and confirmed through in-depth interviews with stakeholders. These were based on three crucial benefits of BT for shrimp consumers, viz. food fraud benefits (Patro et al., 2022; Rowan, 2022), food safety benefits (Hang et al., 2020; Khan et al., 2022; Peng et al., 2023), and sustainability benefits (Howson, 2020; Olsen et al., 2022). Thus, this study had four different treatment groups, as shown in Table 7, which included control (no information provided), food fraud benefits, food safety benefits, and sustainability benefits.

Table 7-Treatment groups used with different information

Treatments	Description	Additional information	Name
1	Only CE questions	No information provided	CONTROL
2	CE questions + food fraud information	By purchasing shrimps with the blockchain certified label it ensures a reduced number of frauds about the product (e.g., wrong country of origin, mislabelling, product substitution, etc.) due to the end-to-end visibility from the farm to the retail store.	FOOD FRAUD BENEFITS
3	CE questions + food safety information	By purchasing shrimps with the blockchain certified label it ensures an improved food safety of the product (e.g., better prevention from food-borne pathogens contaminations, free from chemicals, allergens, antibiotics, etc.) due to the end-to-end visibility from the farm to the retail store.	FOOD SAFETY BENEFITS
4	CE questions + sustainability information	By purchasing shrimps with the blockchain-certified label ensures an improved sustainable production, meaning that the production of shrimps has met with the Best Aquaculture practices standards due to the end-to-end visibility from the farm to the retail store.	SUSTAINAB ILITY BENEFITS

5.3.5 Consumer characteristics to test preference heterogeneity

Moreover, the current studies show that attitudinal factors may shape consumers' perceptions of BT (e.g., Shew *et al.*, 2021;Quan *et al.*, 2018; Acciarini *et al.*, 2023). Thus, a hypothesis was tested about the effect of attitudinal variables on consumers' WTP for different information on

BT benefits. Following the choice tasks, questions that would allow us to collect information on their socio-demographics, habits, and attitudes were added to test our hypotheses concerning attitudinal factors. Specifically, we included questions about:

(i) The effect of gender (GENDER): in line with prior research (e.g., Shew *et al.*, 2021;Quan *et al.*, 2018; Acciarini *et al.*, 2023). The hypothesis is that males have a higher WTP for BT traceable shrimp as compared to females.

(ii) The effect of age (AGE): confirmed by previous studies (e.g., Shew *et al.*, 2021;Esfahbodi, Pang and Peng, 2022; Rao *et al.*, 2023). We hypothesise that younger consumers have a higher WTP for BT traceable shrimps compared to older ones;

(iii) The effect of education (EDUCATION): in line with past studies (e.g., Shew *et al.*, 2021;Esfahbodi, Pang and Peng, 2022; Rao *et al.*, 2023), the hypothesis is that more educated consumers have a higher WTP for BT traceable shrimps compared to less educated consumers;

(iv) The effect of income (INCOME): in line with previous studies (e.g., Shew *et al.*, 2021), the hypothesis is that the higher the income of the consumers, the higher the WTP for BT traceable shrimps than low-income consumers;

(v) The effect of hearing the term BT on whether respondents have heard or not heard (i.e. HEARING) the term 'BT' before could also influence their choices (Rao et al., 2023). Furthermore, consumers who had heard about BT before were asked about their knowledge of BT on a 7-Likert scale from 'Very high knowledge (7) to Very low knowledge and the hypothesis here is that the consumers who heard about BT and had higher knowledge on BT shows higher WTP for BT traceable shrimps than with no knowledge.

(vi) The effect of variable trust to believe that someone is good and honest and will not harm them, and the importance of trust in the food supply chain (TRUST) in line with studies such as (Cao et al., 2021; Howson, 2020). The hypothesis is that consumers who place a higher importance on trust and have lower trust in the current food chain will have higher WTP for BT traceable shrimps compared to consumers who place a lower importance on trust and have higher trust in the food chain.

(vii) Similarly, transparency in the food supply chain (e.g. the quality of being done in an open way without secrets) (TRANSPARENCY) is tested in line with researchers such as (Mazzù et al., 2021; Treiblmaier and Garaus, 2022). The hypothesis is that consumers with higher importance for transparency and with lower transparent ratings for the current food chain will have higher WTP for BT traceable shrimps, compared to the lower importance for transparency and higher transparent ratings for the current food chain.

Moreover, questions such as the importance of different attributes when buying food were put to assess various attributes that consumers consider when buying food, such as taste, naturalness, price, safety, appearance, environmental impact, traceability, etc., on a 7-Likert scale (Asioli, et al., 2022). Additionally, a question on shrimp purchase behaviour, such as the type of shrimps they prefer to buy, with a 4 Likert scale similar to (Clonan et al., 2011), and another question on shrimp buying criteria, such as origin, size, count per pound, shelf life, price, method of production etc. was added in line with other studies (Wirth *et al.*, 2007; Ellis *et al.*, 2016; Yin *et al.*, 2020; Asche, *et al.,*, 2022b).

5.3.6 Hypothesis testing for treatment information groups

To test the research hypotheses, a between-subjects design was implemented, built on the use of four DCE treatments. This study involved examining a CONTROL treatment and three treatment groups namely, FOODFRAUD, FOODSAFETY, and SUSTAINABILITY based on the information on benefits of BT provided to the consumers before they answer DCE. Thus, a statistical test was performed to test the mean differences among the treatment groups. For this, initially, a null hypothesis was formulated, which stated that there was no difference in the means of the control group and each treatment group, respectively. The use of treatments enabled the testing of a series of hypotheses intended to test the difference in WTP based on information provided on the benefits of BT to the respondents. The differences in the WTP between the three treatments involved in our hypotheses (i.e., H01, H02, and H03) were tested by conducting pairwise tests to compare the WTP using data from the two respective treatments involved in the particular hypothesis. Pairwise tests using mixed logit models can compare individual-level parameters that capture heterogeneity in individual preferences, addressing variability (Hensher & Green, 2015). Therefore, as described by several studies, differences in WTPs between treatments involved in a particular hypothesis were tested by conducting pairwise tests on pooled samples, examining interactions between non-price attributes and treatment parameters (d_{treat}), as corroborated with other studies such as (De-Magistris et al., 2013; Bazzani et al., 2017; Scarpa & Willis, 2010). The interactions between non-price attributes (BT, QR and Antibio) and treatment parameters (d_{treat}) were modelled as fixed parameters, whereas the interaction effects were as dummy variables to differentiate one treatment over another (d_{treat}) referring to the studies by Bazzani et al., (2017), and De-Magistris et al., (2013). Accordingly, in this case, it can be specified as follows:

$$U_{njt} = \alpha\,(ASC - PRICE_{njt} + \theta_{n1} BT_{njt} + \theta_{n2}\, QR_{njt} + \theta_{n3}\, ANTIBIO_{njt}) +$$
$$\delta_1 (BT_{nj} \text{ x dtreat}) + \delta_2 (QR_{nj} \text{ x dtreat}) + \delta_3 (ANTIBIO_{nj} \text{ x dtreat}) + \epsilon_{njt} \qquad (5)$$

Referring to Eq. (2) for all attributes, here, ‘dtreat’ is coded as 1 for the first treatment in the analysed hypothesis (i.e., H_{01} for FOODFRAUD, H_{02} for FOODSFTY, H_{03} for

SUSTAINABILITY) and 0 otherwise. The significance of estimated δ coefficients and their signs indicate the effect of the treatment on the WTP for the attribute of interest. Thus, with this new utility specification (Eq.5), the estimates are directly considered the WTP values, and thus the significance of estimated δ along with their signs would help to test differences among WTP between the two treatments involved in the particular hypothesis and then specifying an extended utility with the appropriate set of treatment dummy variables, depending on the hypothesis to be tested as inclined with other researchers (De-Magistris et al., 2013;Bazzani et al., 2017; and Asioli et al., 2021). The following hypotheses were tested:

First, Treatment 1(Control) versus Treatment 2 (Food fraud benefits) was tested to examine the difference in WTP based on the information message provided on the food fraud benefits of BT against the control treatment. Therefore, the following hypothesis was tested,

$$H_{01}(WTP_{Control}-WTP_{Foodfraud}) = 0$$

$$H_{11}(WTP_{Control}-WTP_{Foodfraud}) \neq 0$$

A rejection of null hypothesis H_{01} would confirm that the WTP noted by respondents from the food fraud treatment group and the control treatment group is not equal.

Second, Treatment 1(Control) versus Treatment 3 (Food safety benefits) was tested to examine the difference in WTP based on the information message provided on the food safety benefits of BT against the control treatment. Thus, the following hypothesis was tested,

$$H_{02}(WTP_{Control} - WTP_{Foodsafety}) = 0$$

$$H_{12}(WTP_{Control} - WTP_{Foodsafety}) \neq 0$$

A rejection of null hypothesis H_{02} would confirm that the WTP noted by respondents from the food safety treatment group and the control treatment group are not equal.

Third, Treatment 1(Control) versus Treatment 4 (Sustainability benefits) was tested to examine the difference in WTP based on the information message provided on the sustainability benefits of BT against the control treatment. Thus, the following hypothesis was tested,

$$H_{03}(WTP_{Control}\text{-}WTP_{Sustainability}) = 0$$

$$H_{13}(WTP_{Control}\text{-}WTP_{Sustainability}) \neq 0$$

A rejection of null hypothesis H_{03} would confirm that the WTP noted by respondents from the sustainability treatment group and the control treatment group are not equal.

5.3.7 TRAM framework to explore the technology readiness and acceptance

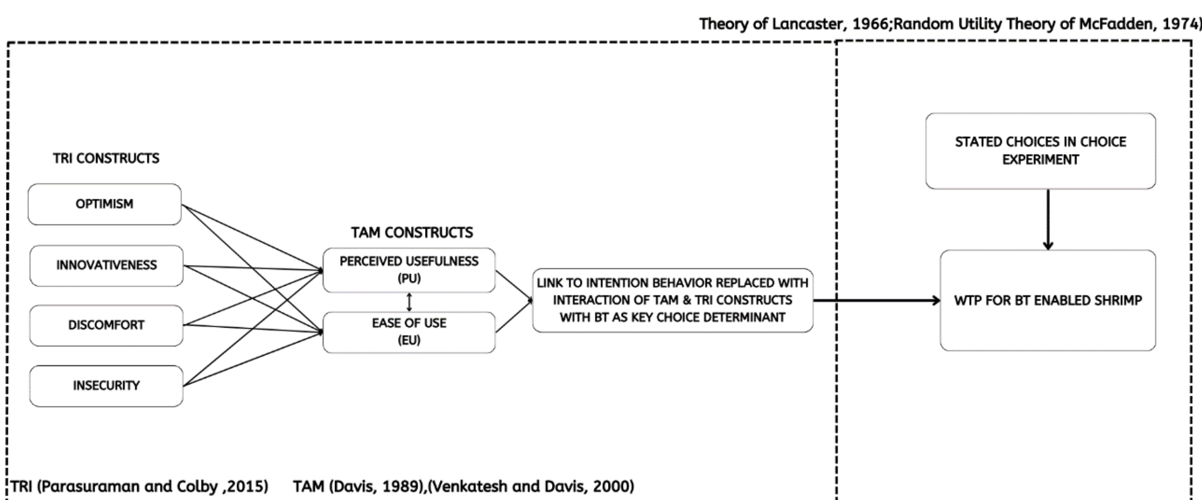
To achieve the fourth research objective, this study adapts a framework called TRAM based on the Technology Acceptance Model (TAM) and Technology readiness index[12] (TRI) following other studies (Buyle et al., 2018; Chen & Lin, 2018; Jin, 2020; Kampa, 2023; Lin & Sher, 2007). The TRAM is an advanced model blending the TAM and TR, wherein TR is the predictor of Perceived usefulness (PU) and Ease of use (EU) of TAM. It is often seen that TAM and TRI models are intuitively accepted as interrelated; however, their measurement scales are different such as PU and EU for TAM constructs denote as specific information technology system which is system-specific, whereas TRI is for general technology beliefs which are individual-specific (Davis, 1985; Parasuraman & Colby, 2014). TAM focuses mainly on the cognitive dimensions of technology response, and TRI emphasises affective and motivational factors. Therefore, TRI was used as a complementary analytical framework to the TAM in analysing attitudes and responses to new technologies (Kolade et al., 2022). Thus, TAM and TRI frameworks are

[12]These questions comprise the Technology Readiness Index (TRI), which is copyrighted by A. Parasuraman and Rockbridge Associates, Inc., 1999. The authors have obtained the requisite permission in this regard.

helpful for an advanced understanding of technology adoption and for filling the gap between the personality traits of people and technology acceptance (Chiu & Cho, 2020).

<u>TRAM framework</u>

This study adapts the TRAM framework, which integrates the constructs of TAM and TRI to explore consumers' intentions and has demonstrated a significant association of technology readiness with perceived usefulness and behavioural intention as highlighted by Lin & Sher, (2007) in the e-service context. The TRAM framework is a more extensive and efficient approach to describing the relationship between readiness to use a new technology and its influences on the user's beliefs about that technology (Jin, 2020). Thus, this study modified the TRAM framework to effect of constructs on consumers' intentions to use and adopt BT as a vehicle to buy shrimp. Here, we adopt a model by Nocella et al. (2010), which integrates the theory of planned behaviour and stated choice analysis. We replaced the key constructs of the TRAM (PU, EU, OPT, INN, INS, and DIS) with the interacted constructs with BT as key choice determinants. Therefore, we inspect if the PU, EU, and technology readiness could affect the consumers' WTP for BT-enabled shrimp. Figure 14 shows an illustrative depiction of the TRAM framework.



(Created by author)

Figure 14-Conceptual framework integrating TAM-TRI and stated choice analysis.

Framework's constructs description

Technology acceptance model (TAM)

TAM is a theory of information systems that is based on the theory of reasoned actions that analyse beliefs and attitudes in social settings and help explain and identify different factors that impact how users accept technology. TAM shares three key dimensions: perceived usefulness (PU), perceived ease of use (EU), and behavioural intention to use (BIU) (Davis, 1985). PU explains the user behavior about a particular technology and how this would make his/her work more efficient. Whereas EU asserts how users believe that his/her work would be effortless, and BIU indicates an individual's requests and efforts to perform a behavior (Davis, 1985). Moreover, TAM is one of the most widely used models by researchers to study the acceptance of new technologies among the public. The original version of this model by Davis, (1985) predicts that Attitudes (the emotional state toward using technology) and Perceived Usefulness (the level at which technology will assist the user) affect intention (Davis, 1989). Thus, a positive attitude and high perceived usefulness raise the intention to use technology (Liu, 2014). In addition to the original TAM model, researchers have developed extended models of the TAM, such as TAM2, which expands the individual user acceptance behaviours by introducing variables such as subjective norms and cognitive instrumental processes, which help to provide a more constructive and nuanced understanding of these behaviours (Venkatesh & Davis, 2000). Meanwhile, TAM3 further extends TAM1 and TAM2 by considering additional constructs such as social influence, facilitating conditions, and cognitive instrumental processes (Venkatesh & Bala, 2008).

This study uses TAM1 over other extended versions as we focused on only fundamental factors (PU and EU) influencing the technology acceptance without considering external and social factors' effects in the model. Moreover, TAM1 has been empirically tested and validated by various researchers and is a powerful and robust model to predict user acceptance in the information systems context (Bong, 2019; Lewis & Hf, 2019; Liu, *et al*., 2020). All variables in the model were measured on a rank scale in the main questionnaire (i.e., strongly disagree (1) to strongly agree (5)), where the higher scores will determine the higher acceptance of BT for shrimp purchase (Bong, et al., 2019).

Technology readiness index (TRI)

Technology Readiness Index (TRI) 2.0 model is used to investigate and explore consumers understanding to adopt and use technologies based on their tendency developed by Parasuraman and Colby (2015). This model includes four dimension: Optimism, Innovativeness, Discomfort, and Insecurity. Optimism and innovativeness are motivators supporting technology readiness. Consumers who fall into the category of optimism believe that innovative technology will increase efficiency, flexibility, and control. Innovativeness describes those who are opinion leaders and pioneers in adopting new technology (Parasuraman & Colby, 2014). Whereas the other two dimensions are discomfort and insecurity and are considered as inhibitors that distracts from technology readiness. Discomfort describes consumers overwhelmed by and perceiving little control with the new technology. People in the category of insecurity do not trust the technology for its functionalities and potential harm (Parasuraman & Colby, 2014). It is seen that the technology by itself can be contradictory at times, for example, when end consumers exhibit contrary behaviour when they use technology, or when technology can assimilate people whilst it can also lead to human separation. Thus, it is important to understand the feelings and paradoxes in adopting a new technology (Mick & Fournier, 1998).

Overall, the correlation between technology readiness and both the constructs of TAM i.e. PU and EU is noted by researchers such as (Jin, (2020); and Walczuch et al., (2007), where they highlighted a close relationship with the enablers of TRI (i.e. Optimism and innovativeness), and inhibitors (Insecurity and Discomfort) with the PU and EU for any given technology. Thus, consumer satisfaction plays a crucial role in determining their intention to use a product or service and is directly linked to subsequent consumer behaviour, including purchase decision-making (Jin, 2020).

Instrument measurement for TRAM

TRI is measured using a full 16-item TRI 2.0 scales (Parasuraman & Colby, 2014) with 4 items for each sub-dimension namely, Optimism (OPT), Innovativeness (INN), Insecurity (INS), and Discomfort (DIS). The scores differ across individuals and therefore their beliefs about various aspects of technology too differ. The TRI construct can be seen as a tool to measure the state of mind to capture the mental enablers and inhibitors which are determinants in an individual's inclination to use new technology (Parasuraman & Colby, 2014).

TAM methodology used to measure using a 6-item scale of TAM1 with 3 items for prime two constructs perceived usefulness (PU), perceived ease of use (EU) (Davis, 1989), using STATA, (2021). These measures were included in the main questionnaire as two separate questions of 5-scale (Kamble et al., 2019; Kolade et al., 2022; Parasuraman & Colby, 2014).

Reliability

Reliability, which is known as a measure of internal consistency of constructs to verify the degree to which the model is affected/unaffected by measurement errors, was evaluated using Cronbach's alpha. It is normally acknowledged that if the Cronbach's alpha is higher than 0.70, the data can be considered reliable (Liu & Ye, 2021).

Correlation analysis

Followed by reliability test, the correlation coefficients were examined to discover the relationships using Pearson correlation between 6 constructs of TRAM (i.e., PU, EU, OPT, INN, INS, & DIS) using STATA (2021) (See Appendix I).

Hypothesis testing

The hypotheses test the effect of TRAM constructs on the behavioural intention of shrimp consumers for WTP. To examine the effects of stated choice experiment results and behavioural intentions on the WTP of BT traceable shrimp, we replaced all TRAM constructs related to behaviour with their interaction terms with BT, which is similar to a study by Nocella et al. (2010). These interaction terms were utilized as independent variables in a mixed logit model (using *mixlogitwtp* command in STATA) to test hypotheses regarding the interaction effects with the dependent variable choice. It is important to note that BT plays a critical role as a determinant of choice in this analysis using STATA, (2021) software. Thus, to estimate the effects of BT on the TRAM constructs, an interaction effect was performed among BT and all the constructs (TAM-PU and EU; and TRI-OPT, INN, INS, and DIS). Thus, extending Eq. (2), the utility MXL model for the TRAM model can be derived as:

$$U_{njt} = ASC + \theta_{n1}PRICE_{njt} + \theta_{n2}BT_{njt} + \theta_{n3}QR_{njt} + \theta_{n4}ANTIBIO_{njt} + \theta_{n5}(PU*BT)_{njt} + \theta_{n6}(EU*BT)_{njt} + \theta_{n7}(OPT*BT)_{njt} + \theta_{n8}(INN*QR)_{njt} + \theta_{n9}(INS*ANTI)_{njt} + \theta_{n10}(DIS*QR)_{njt} + \epsilon_{njt} \quad (6)$$

Where in addition to eq. 2, attributes from interaction terms such as $(PU*BT)_{njt}$ is an interaction term between TAM construct PU (perceived usefulness) and BT showcasing the change in effect of BT label on utility changes with PU. Next, $(EU*BT)_{njt}$ is an interaction term between TAM construct EU (Ease of use) and BT showcasing the change in effect of BT label on utility changes with EU. Similarly, $(OPT*BT)_{njt}$ is an interaction term between TRI construct OPT (optimism) and BT showcasing the change in effect of BT label on utility changes with OPT. Similarly, the other interaction attributes can be described- (INN*QR) as Innovativeness with QR, (INS*ANTI) as Insecurity interaction with antibiotics attributes, and (DIS*QR) with discomfort interacting with QR code. Thus, with this new utility specification (Eq.6), the estimates are directly estimated as the WTP values to identify the impact of the attributes, and therefore, the following hypotheses were proposed:

H1: Perceived usefulness is positively related to the WTP for BT-enabled shrimp.

H2: Perceived ease of use is positively related to the WTP for BT-enabled shrimp.

H3: Optimism is positively related to the WTP for BT-enabled shrimp.

H4: Innovativeness is positively related to the WTP for BT-enabled shrimp.

H5: Discomfort is negatively related to the WTP for BT-enabled shrimp.

H6: Insecurity is negatively related to the WTP for BT-enabled shrimp.

5.4 Results

5.4.1 Socio-demographics

The socio-demographic characteristics of the sample population (866 respondents) are presented in Table 8 across four treatment groups. The table examines the distribution of respondents across different categories based on several variables: Gender, Age, Income, Education, Household Size, and the Child under 18 years of age. For each variable, the table displays the number and percentage of participants within each category. Additionally, statistical tests are provided to assess the significance of mean differences between the control group and groups associated with specific benefits (Food Fraud Benefits, Food Safety Benefits, and Sustainability Benefits).

The percentage of female (51.03%) respondents was slightly higher compared to male (48.96%) overall, which is in line with the latest census data for US females (50.41%) and males (49.59%) (United States Census Bureau, 2021). This was expected considering the grocery shopping responsibilities of the US households where women are the main housekeepers and responsible for buying for the household. (Statista, 2022a). The majority of respondents were from the 60+ age group (25.06%), and although the average income group was diversified, most respondents belonged to the higher average income group ($100,000-$149,000/yr). Furthermore, the highest number of respondents had a bachelor's degree (30.48%), the majority were in two-person households, and the majority had no children (70.90%).

Statistical tests are provided for sociodemographic characteristics, habits, and attitudes in tables to assess the significance of differences between the control group and associated groups. All the test results were non-significant across all treatment groups, showcasing the differences in the median for continuous variables (e.g., Age, and Education). In contrast, there was no association among the categorical variables (e.g., Gender).

Table 8-Socio-demographic characteristics of the sample

VARIABLE	CONTROL (N=234)	FOOD FRAUD BENEFITS (N=210)	FOOD SAFETY BENEFITS (N=210)	SUSTAINAI-BILITY BENEFITS (N=212)	TOTAL (N=866)
Gender	**nº (%)**	**nº (%)**	**nº (%)**	**nº (%)**	**nº (%)**
Male	107(45.73)	101(48.10)	105(50)	111(52.36)	424(48.96)
Female	127(54.57)	109(51.90)	105(50)	101(47.64)	442(51.03)

Pearson chi2(3) = 1.92; Pr = 0.58					
Age	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**
18-29	33(14.10)	27(12.86)	28(13.33)	23(10.85)	111(12.82)
30-39	42(17.95)	34(16.19)	48(22.86)	40(18.87)	164(18.94)
40-49	53(22.65)	49(23.33)	48(22.86)	42(19.81)	192(22.17)
50-59	52(22.22)	43(20.48)	36(17.14)	51(24.06)	182(21.02)
60+	54(23.08)	57(27.14)	50(23.81)	56(26.42)	217(25.06)
Chi-squared with ties (Kruskal Wallis) = 1.82 with 3 d.f.; Pr = 0.60					
Income	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**
Less than $10,000	10(4.27)	12(5.71)	07(3.33)	08(3.77)	37(4.27)
$10,000-$19,000	15(6.41)	09 (4.29)	14(6.67)	08(3.77)	46(5.31)
$20,000-$29,000	25(10.68)	13(6.19)	20 (9.52)	25(11.79)	83(9.58)
$30,000-$39,000	27(11.54)	25(11.90)	26(12.38)	26(12.26)	104(12.01)
$40,000-$49,000	19(8.12)	21(10.00)	12(5.71)	15(7.08)	67(7.74)
$50,000-$59,000	23(9.83)	15(7.14)	17(7.14)	15(7.08)	70(8.08)
$60,000-$69,000	13(5.56)	10(4.76)	12(5.71)	15(7.08)	50(5.77)
$70,000-$79,000	13(5.56)	15(7.14)	15(7.14)	16 (7.55)	59(6.81)
$80,000-$89,000	11(4.70)	14 (6.67)	12(5.71)	11(5.19)	48(5.54)
$90,000-$99,000	12(5.13)	12(5.71)	10(4.76)	07(3.30)	41(4.73)
$100,000-$149,000	38 (16.24)	51(24.29)	31(14.76)	38(17.92)	158(18.24)
$150,000 or more	28(11.97)	13(6.19)	34(16.19)	28(13.21)	103(11.89)
Chi-squared with ties (Kruskal Wallis) = 1.06 with 3 d.f. ; Pr = 0.78					
Education	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**
Elementary/Some High	03 (1.28)	02 (0.95)	01 (0.48)	00(00.00)	06 (0.69)
School	52 (22.22)	50 (23.81)	41 (19.52)	39 (18.40)	182(21.02)
High School Diploma	36 (15.38)	41 (19.52)	35 (16.67)	37 (17.45)	149(17.21)
Some College	07 (2.99)	03 (1.43)	04 (1.90)	04 (1.89)	18 (2.08)
Technical School Diploma	28 (11.97)	17 (8.10)	25 (11.90)	27 (12.74)	97 (11.20)
Associate degree	76 (32.48)	55 (26.19)	67 (31.90)	66 (31.13)	264(30.48)
Bachelor's Degree	24 (10.26)	34 (16.19)	31 (14.76)	33 (15.57)	122(14.09)

Master's Degree	08 (3.42)	08 (3.81)	06 (2.86)	06 (2.83)	28 (3.23)
Doctorate	00(00.00)	00(00.00)	00(00.00)	00(00.00)	00(00.00)
other	00(00.00)	00(00.00)	00(00.00)	00(00.00)	00(00.00)
Chi-squared with ties (Kruskal Wallis) = 2.27 with 3 d.f.; Pr = 0.51	00(00.00)	00(00.00)	00(00.00)	00(00.00)	00(00.00)
Household size (no. of member)	**n⁰**	**n⁰**	**n⁰**	**n⁰**	**n⁰**
1-3	181	164	161	143	669
4-6	48	45	47	43	187
7-9	4	0	2	1	7
10-12	1	1	0	1	3
Chi-squared with ties (Kruskal Wallis) = 0.44 with d.f. 3; Pr = 0.93					
Presence of child under 18y	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**
Child	67 (28.63)	53 (25.24)	63 (30)	69(32.55)	252(29.10)
No Child	167(71.37)	157(74.76)	147(70)	143(67.45)	614(70.90)
Pearson chi2 =2.84 with 3 d.f. ; Pr = 0.41					

5.4.2 Habits

The buying habits of the sample population are presented in Table 9. The table shows the distribution of respondents across different categories based on several variables: Responsibility to buy shrimp, frequency to buy shrimp, shrimp purchase type, shrimp purchase attributes considered while buying. For each variable, the table displays the number and percentage of participants within each category, however shrimp purchase type and attributes rows show the mean and std. deviation of the values across 4 treatment groups.

It was observed that the 79.68% respondents were 'primarily responsible' respondents for food purchase and 20.32% were 'responsible for more than half of food purchase'. Moreover, across all treatment 'once a month' buyers (22.40%) shown highest frequency to buy followed by 'once between 1 to 3 months' (22.29%). Whereas the top choice of shrimp type for consumption was ‘frozen&raw’ with mean value (2.52), followed by ‘fresh&raw’ (2.31) on a 4-likert scale across all treatment groups. Furthermore, in terms of habits of respondent’s majority of them ranked food safety (6.18), shrimp price (6.17), characteristics (5.97) as top three attributes while buying shrimp. On contrary, origin (4.95), producer name (4.70), and brand (4.62) were the least three attributes rated respectively across all treatment groups on a 7-likert scale.

Table 9-Shrimp purchase habits of sample

VARIABLE	CONTROL (N=234)	FOOD FRAUD BENEFITS (N=210)	FOOD SAFETY BENEFITS (N=210)	SUSTAINA--BILITY BENEFITS (N=212)	TOTAL (N=866)
Responsibility to buy.	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**
I am responsible for more than half of food purchases.	45(19.23)	44(20.95)	43(20.48)	44(20.75)	176(20.32)
I am primarily responsible for food purchases.	189(80.77)	166(79.05)	167(79.52)	168(79.25)	690(79.68)
Pearson chi2= 0.25 with 3 d.f.; Pr = 0.96					
Frequency to buy shrimp	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**	**n⁰ (%)**
Once every 6 months	30(12.82)	13(6.19)	19(9.05)	27(12.74)	89(10.28)
Once between 3 to 6 months	40(17.09)	36(17.14)	33(15.71)	31(14.62)	140(16.17)
Once between 1 to 3 months	54(23.08)	48(22.86)	48(22.86)	43(20.28)	193(22.29)
Once a month	52(22.22)	44(20.95)	51(24.29)	47(22.17)	194(22.40)
2-3 times a month	29(12.39)	42(20.00)	41(19.52)	45(21.23)	157(18.13)
Once a week	18(7.69)	16(7.62)	08(3.81)	15(7.08)	57(6.58)

Twice a week	05(2.14)	06(2.86)	05(2.38)	03(1.42)	19(2.19)
3-4 times a week	04(1.71)	03(1.43)	03(1.43)	01(0.47)	11(1.27)
5-6 times a week	01(0.43)	02(0.95)	02(0.95)	00(00.00)	05(0.58)
Everyday	01(0.43)	00(00.00)	00(00.00)	00(00.00)	01(0.12)
Chi-squared with ties (Kruskal Wallis) = 4.02 with 3 d.f. ; Pr = 0.25					
Shrimp purchase type	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
Frozen-Raw	2.50, (0.85)	2.55, (0.86)	2.49, (0.85)	2.54, (0.78)	2.52, (0.83)
Fresh-Raw	2.29, (0.85)	2.35, (0.92)	2.33, (0.82)	2.28, (0.84)	2.31, (0.86)
Frozen-Cooked	2.36, (0.86)	2.34, (0.93)	2.26, (0.84)	2.22, (0.86)	2.29, (0.87)
Fresh-Cooked	2.23, (0.82)	2.20, (0.85)	2.07, (0.74)	2.12, (0.88)	2.16, (0.83)
Chi-squared with ties (Kruskal Wallis) = 2.82; Pr = 0.41					
Shrimp purchase attributes	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
Food Safety	6.06, (1.24)	6.32, (0.91)	6.20, (1.09)	6.14, (1.00)	6.18, (1.07)
Shrimp Price	6.14, (1.14)	6.25, (0.93)	6.18, (0.97)	6.11, (1.09)	6.17, (1.04)
Characteristics	5.93, (1.02)	6.10, (0.94)	6.01, (0.96)	5.86, (1.13)	5.97, (1.02)
Shelf Life	5.79, (1.40)	6.10, (1.01)	5.85, (1.26)	5.79, (1.21)	5.88, (1.24)
Size	5.82, (1.04)	5.81, (1.10)	5.76, (1.04)	5.85, (1.08)	5.81, (1.06)
Color	5.68, (1.16)	5.84, (1.12)	5.71, (1.19)	5.64, (1.18)	5.72, (1.16)
Ingredients	5.60, (1.40)	5.80, (1.15)	5.72, (1.25)	5.57, (1.25)	5.67, (1.27)
Count					

Weight	5.62, (1.20)	5.69, (1.16)	5.67, (1.22)	5.67, (1.17)	5.66, (1.18)
Production method	5.53, (1.22)	5.69, (1.18)	5.57, (1.13)	5.52, (1.22)	5.58, (1.19)
Nutritional	5.44, (1.38)	5.49, (1.26)	5.54, (1.31)	5.51, (1.25)	5.49, (1.31)
Information	5.32, (1.40)	5.63, (1.25)	5.52, (1.37)	5.38, (1.38)	5.46, (1.35)
Sustainable	5.26, (1.45)	5.34, (1.47)	5.28, (1.51)	5.16, (1.44)	5.26, (1.47)
Certification	5.17, (1.35)	5.35, (1.35)	5.33, (1.30)	5.09, (1.41)	5.23, (1.35)
Variety	5.20, (1.49)	5.22, (1.46)	5.14, (1.53)	5.03, (1.57)	5.15, (1.51)
Instructions	5.09, (1.56)	5.27, (1.49)	4.99, (1.54)	4.95, (1.46)	4.95, (1.46)
Origin	4.73, (1.50)	4.78, (1.47)	4.70, (1.57)	4.60, (1.49)	4.70, (1.51)
Producer name	4.52, (1.49)	4.82, (1.50)	4.60, (1.40)	4.54, (1.52)	4.62, (1.48)
Brand nameChi-squared with ties *(Kruskal Wallis) =* 5.57 with 3 d.f ; Pr = 0.13					

5.4.3 Attitudes

The buying attitudes of the sample population are presented in Table 10. The table shows the distribution of respondents across different categories based on several variables: knowledge of BT, knowledge of BT on the scale, technology acceptance model, technology readiness index, food values, trust and transparency attitudes. However, in the context of BT adoption, attitudes toward BT-traceable shrimps represent the psychological evaluation of the technology. However, these attitudes are shaped by various antecedents, including perceived transparency, trust, and technology usability. Table 10 includes several variables, some of which are attitudinal, while others either influence or result from attitudes (*description in section 5.1.2*).

For knowledge of the BT variable, the table displays the number and percentage of participants within each category. However, all other variables are presented with their mean and std. deviation of the values across four treatment groups. Additionally, statistical tests are provided to assess the significance of differences between the control group and groups associated with specific benefits, as in Tables 8 and 9. Regarding knowledge of BT, respondents with no knowledge of BT (55.31%) outnumbered the ones who had knowledge of about BT (44.69%) across all treatment groups, which is acceptable as BT is a relatively new technology in the discussion. Furthermore, while capturing the attitudes of consumers on new technology acceptance, respondents from treatment 1 noted the highest value for constructs such as perceived usefulness (PU) (3.57) and perceived ease of use (EU) 1 (3.82).

Next, a variable in consumer attitudes -food values considered by the respondents while shopping for food was examined and it was found that 'food safety' was ranked as the top value (6.45), followed by taste (6.38), and price (6.05) whereas, fairness (5.28), traceability (5.24), and tradition (4.75) were least three values among all as shown in Table-5.3 across all four treatments. Another variable of consumer attitude on trust and transparency of food supply chains was captured wherein respondents from treatment 1 (4.07) noted the highest rank for 'trust' being important in the food supply chain, followed by treatment 2 (4.06). Meanwhile, the participants from treatment groups 2 and 3 respectively ranked as believing that current food supply chains are trustworthy, with 5.14 and 5.12 mean values respectively. Similarly, consumer attitude on transparency in the food supply chain was captured in which respondents from treatment 1 (5.76) noted the highest rank for 'transparency' being important in the food supply chain followed by both control treatment and treatment 2 (5.76), moreover treatment 1 ranked highest for belief that the current food supply chains are transparent (4.89), followed by control treatment group (4.88).

Table 10-Consumer Attitudes

VARIABLE	CONTROL (N=234)	FOOD FRAUD BENEFITS (N=210)	FOOD SAFETY BENEFITS (N=210)	SUSTAINA-BILITY BENEFITS (N=212)	TOTAL (N=866)
Knowledge of BT	**n^0 (%)**	**n^0 (%)**	**n^0 (%)**	**n^0 (%)**	**n^0 (%)**
No	129 (55.13)	118 (56.19)	108 (51.43)	124 (58.49)	479 (55.31)
Yes	105 (44.87)	92 (43.81)	102 (48.57)	88 (41.51)	387 (44.69)
Pearson chi2(3) = 2.21 Pr = 0.52					
Knowledge of BT on Scale	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
Chi-squared with ties (Kruskal wallis) = 3.04 with 3 d.f. Pr = 0.38	3.84, (1.53) n^0 =101	4.07, (1.63) n^0 =92	4.06, (1.64) n^0=103	3.82, (1.54) n^0=91	3.94, (1.58) n^0 =387
Technology Accept. Model	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
PU	3.33, (0.94)	3.53, (0.92)	3.46, (1.00)	3.43, (0.97)	3.49, (0.96)
EU	3.72, (0.81)	3.72, (0.79)	3.82, (0.88)	3.51, (0.81)	3.71, (0.88)
Chi-squared with ties (Kruskal Wallis) = 3.02 with 3 d.f. Pr = 0.33					
Technology Readiness Index	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
OPT	3.89, (0.68)	3.86, (0.75)	3.84, (0.79)	3.41, (0.92)	3.85, (0.75)
INN	3.31, (0.86)	3.32, (1.00)	3.30, (0.98)	3.83, (0.84)	3.34, (0.94)
INS	2.84, (0.79)	2.74, (0.80)	2.81, (0.77)	2.89, (0.74)	2.82, (0.78)

DIS *Chi-squared with ties (Kruskal Wallis) = 2.88 with 3 d.f.* *Pr= 0.44*	3.31, (0.86)	3.14, (0.94)	3.17, (0.84)	3.23, (0.82)	3.22, (0.87)
Food Values	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
Safety	6.34, (1.08)	6.60, (0.80)	6.47, (0.85)	6.41, (0.93)	6.45, (0.93)
Taste	6.34, (0.97)	6.47, (0.84)	6.40, (0.85)	6.34, (1.02)	6.38, (0.92)
Price	6.02, (1.08)	6.19, (0.92)	6.01, (1.01)	6, (1.06)	6.05, (1.02)
Nutrition	5.91, (1.12)	6.10, (1.09)	5.97, (0.98)	5.94, (1.05)	5.98, (1.07)
Appearance	6.01, (1.08)	6.08, (1.06)	5.98, (1.05)	5.90, (1.13)	5.97, (1.08)
Naturalness	5.33(1.29)	5.56(1.17)	5.53(1.18)	5.40(1.24)	5.45, (1.22)
Origin	5.34(1.35)	5.51(1.18)	5.35(1.40)	5.30, (1.26)	5.37(1.30)
Convenience	5.38, (1.34)	5.46, (1.08)	5.25, (1.19)	5.26, (1.22)	5.34(1.19)
Environment	5.34, (1.39)	5.30, (1.48)	5.25, (1.46)	5.30, (1.46)	5.30, (1.34)
Fairness	5.26, (1.43)	5.43, (1.30)	5.18, (1.48)	5.25, (1.39)	5.28, (1.40)
Traceability	5.25, (1.39)	5.32, (1.25)	5.20, (1.51)	5.20, (1.33)	5.24, (1.37)
Tradition	4.85, (1.47)	4.88, (1.49)	4.57, (1.42)	4.69, (1.42)	4.75, (1.46)
Chi-squared with ties = 6.28 with 3 d.f. ; *Pr = 0.09*					
Trust importance	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
Chi-squared with ties (Kruskal Wallis) = 4.24 with 3 d.f.; *Pr = 0.23*	3.84, (1.53)	4.07, (1.63)	4.06, (1.64)	3.82, (1.54)	3.94, (1.58)
Trust Belief	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**	**Mean, (std. dev)**
Chi-squared with ties (Kruskal Wallis) = 0.99 with 3 d.f.;	5.10, (1.12)	5.14, (1.16)	5.12, (1.14)	5.04, (1.15)	5.10, (1.14)

Pr = 0.8033					
Transparency importance *Chi-squared with ties (Kruskal Wallis) = 2.39 with 3 d.f.; Pr = 0.49*	**Mean, (std. dev)** 5.76, (1.16)	**Mean, (std. dev)** 5.77, (1.19)	**Mean, (std. dev)** 5.76, (1.07)	**Mean, (std. dev)** 5.64, (1.15)	**Mean, (std. dev)** 5.73, (1.14)
Transparency Belief *Chi-squared with ties (Kruskal Wallis) = 2.60 with 3 d.f.; Pr = 0.45*	**Mean, (std. dev)** 4.88, (1.40)	**Mean, (std. dev)** 4.89, (1.34)	**Mean, (std. dev)** 4.72, (1.25)	**Mean, (std. dev)** 5.64, (1.15)	**Mean, (std. dev)** 4.82, (1.33)

5.4.4 Results-choice models

Estimation results -main effects

The results from the estimation of the MXL models using Equation (2) in WTP space using the main effects are exhibited in Table 11. The estimates (WTP) shown are for BT label, QR code, No antibiotics ever label and Price, Opt-out, and respective significance values (p-value) for the attributes in USD \$/lb. The null hypothesis that all coefficients are zero is rejected by a likelihood ratio test (p-value < 0.01). All coefficients of the main effect variables are significantly different from zero at a 1% significance level, which implies that attributes chosen in this research (i.e. BT, QR, ANTIBIO & PRICE) are all considered relevant attributes by consumers. Furthermore, the derived standard deviation of all the attributes is statistically significant at 1 % (p value: 0.00), which allows preference heterogeneity among consumers, thus suggesting that there is a heterogeneity for valuation of attributes and WTP among shrimp consumers. This shows that products with blockchain, QR, and no antibiotics ever labels illustrate to gain a premium price in the market compared to the existing shrimp products without these labels. Thus, consumers are willing to pay a good premium for all the shrimps with blockchain, QR, and No antibiotics ever labels.

The results suggest that the mean estimate for the 'Opt-out' option was found negative, and significant at a 1% significance level, dictating that consumers tended to prefer one of the two product alternatives against the opt-out option. On an average, the results show that across all treatment groups, consumers tended to prefer low price shrimp products (WTP: -0.97$/lb, -1.00$/lb, -0.92$/lb, -0.91$/lb respectively for treatments 1,2,3,4 respectively at p-value: 0.00) with all the labels such as BT label, QR code, and no antibiotics ever. Next, it was observed that the BT label is strongly preferred with the highest value across all treatment groups followed by no antibiotics ever label, and lastly QR code. In particular, respondents from treatment group 3 (FOOD SAFETY) who read information on the food safety benefits of BT showed the highest WTP for the BT label (WTP: 4.16 $/lb; p-value<0.01), followed by the antibiotics label (WTP:3.67$/lb), and QR code (WTP:0.93$/lb; p-value<0.01). Similar valuation of attributes and their WTP are obtained across all treatment groups as shown in Table 11.

Table 11-Estimated coefficients from the MXL models with main effects (WTP space)

Variables	**CONTROL (N=234)**		**FOOD FRAUD (N=210)**		**FOOD SAFETY (N=210)**		**SUSTAINA-BILITY (N=212)**	
	WTP ($/lb) (SE)	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**
Block-chain	3.54*** (0.40)	6.81***	3.61*** (0.44)	6.34***	4.16*** (0.47)	5.53**	3.10*** (0.31)	5.20***

QR	0.79*** (0.25)	1.66***	0.77*** (0.25)	-1.27***	1.01*** (0.28)	2.05***	0.93*** (0.23)	4.69***
Antibiotic	4.03*** (0.31)	4.42***	3.45*** (0.40)	4.14***	3.67*** (0.31)	4.67***	3.84*** (0.32)	4.70***
Price	-0.97*** (0.14)	1.27***	-1.00*** (0.12)	1.34***	-0.92*** (0.11)	1.09***	-0.91*** (0.12)	1.07***
Opt-out	-10.90*** (0.24)		-10.00*** (0.25)		-9.58*** (0.26)		-9.70*** (0.26)	
Model fit statistics								
N. obs.	5616		5040		5040		5088	
Wald chi2	2348.40		3183.08		2634.63		3262.68	
Prob > chi2	0.00		0.00		0.00		0.00	
logL	-1445.22		-1345.22		-1309.48		-1319.71	
df	9		9		9		9	
AIC	2908.45		2708.44		2636.96		2657.43	
BIC	2968.15		2767.16		2695.68		2716.24	

Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion; df, degree of freedom; logL, log likelihood function; N. obs., number of observations; SD, standard deviation; SE, standard error; LR chi2, Likelihood Ratio Chi-Square test.

*Note: ***, **, * significance, respectively, at 1%, 5%, and 10% levels.*

Estimation results- main and interaction effects

The results from the estimation of the MXL models using Equation (3) in WTP space using the main effects and the interaction effects are shown in Table 12. The estimates (WTP) shown are for BT label, QR code, No antibiotics ever label, Price, Opt-out, and respective interaction variables among all attributes, along with respective significance values for the attributes (p-value). Price and opt-out coefficients were negative and significant at p-value<0.01 similar to the previous section on main effects. Notably, all the attributes (i.e. BT, QR, ANTIBIO & PRICE) have significant SDs (p-values: 0.00), suggesting the existence of consumer heterogeneity across groups.

Only consumers from the treatment group FOOD FRAUD valued shrimp with BT label and QR code which implies that consumers pay attention to food fraud benefits of BT and consider tracing the shrimp product using QR code (WTP: +0.42$/lb, p-value<0.01). On contrary, consumers from treatment group FOODSAFETY shown preference for shrimp with all three labels such as BT label with No antibiotics label (WTP: +0.55$/lb, p-value<0.01) and QR codes (WTP: +0.40$/lb, p-value<0.01) which shows a good impact of food safety benefits of BT on consumers. This shows consumers get more utility in buying shrimp with a combination of all three labels that ensures the food safety of the shrimps they buy. This is in line with other studies on shrimp, which outlined consumer preferences for enhanced food safety with higher WTP (Khan, 2018; Yin et al., 2022).

Furthermore, surprisingly, consumers from treatment group SUSTAINABILITY showed a preference for shrimp with only QR codes (WTP: +0.40$/lb, p-value<0.01), which shows no impact of the sustainability benefits of BT on consumers. The reason for this might be they are unaware of the process in shrimp farming and its environmental impact. This is contradictory to the previous studies where consumers have shown higher WTP for sustainability labels, Phong et al., (2023) and Xuan, (2021).

Moreover, the price has shown negative influence on BT across all treatment groups with high significance such as CONTROL (WTP: -0.61/lb, p-value<0.01), FOODFRAUD (WTP: -0.50$/lb, p-value<0.05), FOODSAFETY (WTP: -0.58$/lb, p-value<0.01), SUSTAINABILITY (WTP: -0.48$/lb, p-value<0.05), which indicates that higher-priced alternatives would decrease consumer utility. However, in contrast, a positive effect of price was seen on QR code labels across all the treatment groups, which indicates (WTP: +0.50$/lb, p-value<0.01), that lower prices with QR code would increase utility for consumers.

Table 12-Estimated coefficient from the MXL models with interaction effects

Variables	CONTROL (N=234)		FOOD FRAUD (N=210)		FOOD SAFETY (N=210)		SUSTAINA-BILITY (N=212)	
	WTP ($/lb) (SE)	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**
Blockchain	9.59*** (2.50)	6.54***	9.62* (3.89)	3.89***	9.98*** (6.64)	6.64***	10.06*** (3.75)	-5.31***
QR	-5.15*** (1.29)	1.75***	-5.10*** (1.05)	-1.15***	-4.78*** (3.63)	1.79***	-4.89*** (1.47)	-1.21
Antibiotics	1.95 (1.95)	4.11***	1.89 (1.92)	5.10***	3.78** (2.20)	4.14***	3.82* (2.15)	5.00***
Price	-0.88*** (0.05)	1.29***	-0.92*** (0.12)	1.15***	-0.87*** (0.17)	1.27***	-0.91*** (0.18)	1.14***
QRxBT	3.09** (1.45)		0.42*** (1.41)		3.13** (1.48)		0.39 (1.43)	
ANTIxBT	0.45 (1.39)		-1.15*** (1.15)		0.55*** (1.37)		-1.11 (1.22)	
ANTIxQR	-0.83 (1.30)		0.01 (1.16)		-0.87 (1.29)		0.01 (1.15)	
PRxBT	-0.61*** (0.24)		-0.50** (0.24)		-0.58*** (0.24)		-0.48** (0.24)	
PRxQR	0.45*** (0.10)		0.43*** (0.13)		0.40*** (0.09)		0.45*** (0.11)	
PRxANTI	0.08 (0.11)		-0.18 (0.13)		0.08 (0.11)		-0.07 (0.13)	
Opt-out	-9.08**	-	-10.26***	-	-11.34***	-	-10.53***	-

	(0.15)		(0.78)		(1.07)		(0.88)	
Model fit statistics								
N. obs.	5616	-	5040	-	5040	-	5088	-
Wald chi2	3261.16	-	3952.65	-	4265.76	-	3080.35	-
Prob > chi2	0.00	-	0.00	-	0.00	-	0.00	-
logL	-1432.74	-	-1324.95	-	-1287.80	-	-1300.11	-
df	15	-	15	-	15	-	15	-
AIC	2725.61	-	2410.29	-	2605.61	-	2630.23	-
BIC	2783.51	-	2749.20	-	2703.49	-	2728.25	-

Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion; df, degree of freedom; logL, log likelihood function; N. obs., number of observations; SD, standard deviation; SE, standard error; LR chi2, Likelihood Ratio Chi-Square test. QRxBT-interaction terms of qr & blockchain; ANTIxBT- interaction terms of antibiotics & blockchain labels;ANTIxQR- interaction terms of antibio & qr;PRxBT- interaction terms of price & blockchain label; PRxQR- interaction terms of price & qr label; PRxANTI- interaction terms of price& antibiotics label.

*Note: ***, **, * significance, respectively, at 1%, 5%, 10% levels.*

<u>Estimation results- main effects, interaction effects and consumer characteristics</u>

The results from the estimation of the MXL models using Equation (4) in WTP space using the main effects and the consumer characteristics are shown in Table 13. The estimates (WTP) shown are for Blockchain label, QR code, No antibiotics ever label, Price, Opt-out, and interaction variables of consumer characteristics such as GENDER, AGE, INCOME, EDUCATION, HEARING, CHILDREN, TRUST, TRUSTBELIEF, TRANSPARENCY, TRANSPBELIEF all interacted with BT, along with respective significance values for the attributes (p-value).

Interesting results were are found such as consumers from treatment group 2 (FOOD FRAUDS) shows that younger generation (AGE*BT-WTP: -0.62$/lb, p-value<0.01), with higher education (EDU*BT-WTP: -0.62$/lb, p-value<0.01) who have heared about BT (HEAR*BT-WTP: +0.51$/lb, p-value<0.05), and who believes that trust (TRSTBLF*BT-WTP: +1.96$/lb, p-value<0.01) and transparency are highly important in the food supply chain (TRNSPBLF*BT-WTP: +2.15 $/lb, p-value<0.01) chose BT enabled shrimps. However, Consumers from group 3 (FOOD SAFETY) were male (GEN*BT- WTP: +2.21$/lb, p-value<0.01) with higher income (INC*BT- WTP: +0.28 $/lb, p-value<0.01) and although haven't heard about BT (HR*BT-WTP: -1.91 $/lb, p-value<0.01) preferred paying premium price for BT labels as shown in Table 13.

Table 13-Estimated coefficient from the MXL models with consumer characteristics effects

Variables	CONTROL (N=234)		FOOD FRAUD (N=210)		FOOD SAFETY (N=210)		SUSTAINA-BILITY (N=212)	
	WTP ($/lb) (SE)	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**
Blockchain	-7.27** (3.72)	-6.25***	-0.82 (1.88)	6.06***	-1.36* (0.76)	-4.77***	-7.78 (1.68)	4.47***
QR	1.31*** (0.29)	-1.97***	1.04*** (0.23)	1.27***	0.33*** (0.08)	2.55***	0.60*** (0.22)	1.29***
Antibiotics	3.63*** (0.09)	4.85***	4.43*** (0.30)	5.16***	0.91*** (0.10)	4.37***	3.94*** (0.36)	5.20***
Price	-1.13*** (0.09)	0.95***	-1.05*** (0.14)	1.20*** (0.20)	-1.01*** (0.09)	0.98***	-0.86*** (0.11)	1.15***
Opt-out	-11.33*** (0.34)	-	-9.66*** (0.24)	-	-9.90***	-	-9.87*** (0.24)	-

					(0.23)			
GEN*BT	-0.06 (0.26)	-	1.00 (0.68)	-	2.21*** (0.65)	-	-1.61* (0.90)	-
AGE*BT	0.23 (0.45)	-	-0.62*** (0.21)	-	-0.15 (0.20)	-	-0.14 (0.21)	-
INC*BT	0.17 (0.12)	-	-2.75*** (0.50)	-	0.28*** (0.09)	-	-0.13* (0.07)	-
EDU*BT	-0.37* (0.22)	-	5.59*** (0.86)	-	-0.04 (0.18)	-	0.06 (0.13)	-
HEAR*BT	0.39 (0.88)	-	0.51** (0.24)	-	-1.91*** (0.23)	-	-0.05* (0.55)	-
CHILD*BT	-0.83 (0.88)	-	-0.75* (0.41)	-	-0.18 (0.23)	-	-1.12 (0.21)	-
TRST*BT	0.14 (0.41)	-	-0.41* (0.10)	-	0.70 (0.16)	-	-0.13 (0.25)	-
TRSTBLF*BT	0.19 (0.70)	-	1.96*** (0.29)	-	0.32 (0.12)	-	0.69*** (0.25)	-
TRANSP*BT	1.38*** (0.45)	-	0.58* (0.21)	-	0.23 (0.44)	-	1.32*** (0.26)	-
TRANSPBLF*BT	-0.05 (0.49)	-	2.15*** (0.25)	-	0.26 (0.40)	-	0.69 (0.26)	-
Model fit statistics								
N. obs.	5616		5040		5040		5088	
Wald chi2	2643.53		5124.90		4778.72		3602.88	
Prob > chi2	0.00		0.00		0.00		0.00	
logL	-1437.55		-1335.99		-1307.26		-1310.17	
df	19		19		19		19	
AIC	2913.11		2709.98		2652.52		2658.34	
BIC	3039.14		2833.95		2776.50		2782.49	

Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion; df, degree of freedom; logL, log likelihood function; N. obs., number of observations; SD, standard deviation; SE, standard error; LR chi2, Likelihood Ratio Chi-Square test. GENxBT-interaction terms of gender & blockchain label;, AGExBT- interaction terms of age & blockchain labels; INCxBT- interaction terms of income & blockchain label; EDUxBT- interaction terms of education & blockchain label; HxBT- interaction terms of hearing of term blockchain & blockchain label; CHILDxBT- interaction terms of no. of children under 18 yr old in household & blockchain label; TRSTxBT- interaction terms of trust variable & blockchain label; TRSTBLFxBT- interaction terms of belief on trust in current fish supply chains & blockchain label TRANSPxBT- interaction terms of transparency in fish supply chain variable & blockchain label; TRANSPBLFxBT- interaction terms of belief on transparency variable & blockchain label TAM-Technology acceptance Model index value; TRI-Technology readiness index value

*Note: ***, **, * significance, respectively, at 1%, 5%, and 10% levels.*

Estimation results- Hypothesis testing of communication message effect

The results from the hypothesis tested to explore if the information message provided to different treatment groups against control treatment (no information) significantly affects shrimp consumers WTP. Thus, we estimated three separated models to test: (1) the first null hypothesis $H_{01}(WTP_{Control}-WTP_{Foodfraud}) =0$; (2) the second null hypothesis $H_{02}(WTP_{Control}-WTP_{Foodsafety}) =0$; *and* (3) the third null hypothesis is $H_{03}(WTP_{Control}-WTP_{Sustainability}) =0$; using pooled data from treatments. Table 14 reports estimates from the main effects and the interaction between the non- price attributes BT, antibio, and QR, and the treatment (dtreat) parameters. Column 1 shows that null hypothesis $H01(WTPControl-WTPFoodfraud) =0$ can be rejected as the interaction between BT and treatment variable is significant. Whereas it can be seen that consumers are willing-to-pay slightly higher for BT traceable shrimp after reading the information on food fraud benefits of BT (+0.17$/lb), compared to the consumers who read no communication message on BT. Similarly, as seen in column 2, the second null hypothesis $H_{02}(WTP_{Control}-WTP_{Foodsafety}) =0$ can also be rejected as the interaction between BT and treatment variable is significant (+0.22$/lb) whi,ch too shows higher WTP by the consumers from this treatment group after reading food safety benefits of BT compared to the consumers who read no communication message. However, column 3 showcases that the third null hypothesis $H03(WTP_{Control}\text{-}WTP_{Sustainability}) = 0$, also be rejected as the interaction between BT and treatment variable is significant (-0.28$/lb, p-value<0.05). However, the negative sign of the estimate indicates that consumers' WTP from sustainability treatment group is significantly lower compared to the consumers who reading no communication message. All the results are corroborated with similar other studies (Asioli et al., 2021; Bazzani et al., 2017; De-Magistris et al., 2013).

Table 14-Hypothesis testing for effect of information on WTP

Variables	H01: ($WTP_{CONTROL}$– $WTP_{FOODFRD}$) =0		H02:($WTP_{CONTROL}$ – $WTP_{FOODSFTY}$) =0		H03: ($WTP_{CONTROL}$ – $WTP_{SUSTNBLTY}$) =0	
	WTP ($/lb) (SE)	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**
Blockchain	10.54*** (1.00)	9.21***	4.12*** (0.41)	5.41***	3.55*** (0.67)	9.21***
QR	8.23*** (0.71)	-5.15***	1.56*** (0.36)	2.23***	1.15*** (0.29)	-5.15***
Antibiotic	11.51*** (0.85)	7.37***	3.52*** (0.49)	4.91***	3.65*** (0.43)	7.37***
Price	-2.29*** (0.06)	0.56***	-1.75*** (0.04)	1.00***	-1.06*** (0.07)	0.56***
Opt-out	-12.41*** (0.43)		-11.83*** (0.39)		-10.47*** (0.21)	
Interactions with treatments						
Blockchain X dtreat	0.18*** (1.35)		0.25*** (0.60)		-0.20*** (0.89)	
Antibio X dtreat	-1.06		-0.39		0.31**	

	(1.15)	(0.52)	(0.76)
QR code X dtreat	-1.55*	-0.68	-0.41
	(1.01)	(0.49)	(0.34)
Model fit statistics			
N. obs.	10,656	10,656	10,704
Wald chi2	1458.93	5380.89	4258.58
Prob > chi2	0.00	0.00	0.00
logL	-3147.30	-2762.55	-2779.33
df	12	12	12
AIC	6316.60	5549.11	5582.67
BIC	6396.61	5636.40	5670.01

Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion; df, degree of freedom; logL, log-likelihood function; N. obs., number of observations; SD, standard deviation; SE, standard error; LR chi2, Likelihood Ratio Chi-Square test. Blockchain X dtreat -interaction terms of BT & treatment; Antibio X dtreat - interaction terms of antibiotics & treatment labels; QR code X dtreat - interaction terms of antibio & treatment.

*Note: ***, **, * significance, respectively, at 1%, 5%, and 10% levels.*

Estimation results- TRAM model from the MXL models across four treatments

The results from the estimation of the MXL models in WTP space using the main effects and the TRAM constructs are shown in Table 15. The estimates (WTP) shown are for the BT label, QR code, No antibiotics ever label, Price, Opt-out, and interaction variables of consumer characteristics such as PU, EU, OPT, INN, INS, and DIS, all interacted with BT, along with respective significance values for the attributes (p-value). The Cronbach's alpha for all the TRAM constructs of PU and EU, OPT, INN, INS, and DIS was found to be >0.86 (0.88, 0.89, 0.87, 0.89, 0.88, and 0.90 respectively), which shows a strong reliability of the scale and very high internal consistency of the model where scale measured the same underlying constructs.

Overall, findings show that across all treatments, PU was positively related to the WTP for BT-enabled shrimp significantly, which does not reject the hypothesis (H1) (PU*BT: +4.31$/lb, +3.26 $/lb, +2.82$/lb, +3.02$/lb, at p-value<0.01). Thus, this indicates that perceived usefulness has an influence on paying higher prices for BT-enabled shrimp. However, as per findings only for treatments 2(FOOD FRAUD) (EU*BT: +0.43$/lb, p-value<0.1) and 3 (SUSTAINABILITY) (EU*BT: +0.88 $/lb, p-value<0.1) shown positive relation for EU and WTP, thus not rejecting H2 completely. Thus this accepted hypothesis H1 and H2 indicates that usefulness would influence the perception of usefulness which indirectly influences BT adoption by the consumers, which is corroborated by similar other studies such as (Esfahbodi et al., 2022; Grover et al., 2019; Kamble et al., 2019).

Moreover, the results for TRI constructs such as contributors (OPT and INN) and inhibitors (INS and DIS)(Parasuraman & Colby, 2014) were interesting, as OPT (OPTIMISM) showed a positive relation to the WTP across treatment 1 (CONTROL) and treatment 3(FOOD SAFETY) with WTP (OPT*BT) of +1.08$/lb, and +0.58$/lb respectively, at p-value<0.05 Thus H3 could not be rejected. Similarly, INN (INNOVATIVENESS) showed a positive relation with WTP for treatments 1 (CONTROL), 2(FOODFRAUD), and 4(SUSTAINABILIY) with coefficients (INN*BT- WTP:+0.20$/lb, +0.93$/lb, +0.17 all at p-value<0.5) respectively. Furthermore, the first inhibitor such as INS(INSECURITY), noted a negative coefficient as expected which shows a negative relation with WTP, however only treatment 3 (FOOD SAFETY) showed significance (INS*BT- WTP: -0.44$/lb, p-value<0.05). Similarly, for another inhibitor, DIS(DISCOMFORT) results show a negative relation across all treatment group; however, with only treatment 2 (FOOD SAFETY) at 1 % significant level (DIS*BT WTP: -1.26$/lb, p-value<0.01),) which shows that. Therefore, hypothses, H3, H4, H5, and H6 are supported and cannot be rejected, as in line with other studies such as (Kamble et al., 2019; Peeters, 2013; Tayal et al., 2021). Thus, the results gained from the TRAM model give direction for BT acceptance in the existing shrimp supply chain overall.

Table 15-The estimated coefficient for the TRAM model across four treatment groups

Variables	CONTROL (N=234)		FOOD FRAUD (N=210)		FOOD SAFETY (N=210)		SUSTAINA-BILITY (N=212)	
	WTP ($/lb) (SE)	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**	***WTP ($/lb) (SE)***	**SD**
Opt-out	-11.04 (0.43)	-	-9.97*** (0.27)	-	-9.73*** (0.29)	-	-9.76*** (0.27)	-
Blockchain	-16.40*** (0.84)	-4.08*** (0.40)	-6.54 (3.73)	-0.08 (0.33)	-8.05*** (0.76)	4.62*** (0.47)	2.29 (3.31)	-4.28*** (0.41)
QR	0.31*** (0.27)	-1.66*** (0.52)	0.79*** (0.33)	-0.01 (0.28)	0.90*** (0.31)	-2.12*** (0.40)	0.85*** (0.26)	-1.46*** (0.36)
Antibiotics	0.83*** (0.06)	4.50*** (0.38)	3.48*** (0.40)	0.60*** (0.13)	3.47*** (0.39)	4.32*** (0.28)	3.80*** (0.37)	4.82*** (0.37)
Price	-0.28*** (0.02)	1.11*** (0.01)	-1.03*** (0.02)	0.25*** (0.01)	-0.95*** 0.10	1.01*** (0.13)	-0.96*** (0.11)	1.05*** (0.15)
PUxBT	4.31*** (0.78)	-	3.26*** (0.86)	-	2.82*** (0.63)	-	3.02*** (0.52)	-
EUxBT	-0.92 (0.92)	-	0.45* (0.22)	-	-0.14 (0.82)	-	0.88* (0.51)	-
OPTxBT	1.08** (0.85)	-	-0.85* (0.86)	-	0.58** (0.79)	-	-0.86* (0.69)	-
INNxBT	0.20* (0.53)	-	0.93* (0.54)	-	-0.29 (0.47)	-	0.17* (0.57)	-
INSxBT	-1.25* (0.25)	-	-0.59 (0.60)	-	-0.44* (0.73)	-	-0.86* (0.60)	-
DISxBT	-0.02 (0.11)	-	-1.26*** (0.49)	-	-0.73** (0.62)	-	-0.39 (0.50)	-
Model fit statistics								
N. obs.	5616		5040		5040		5088	

LR chi2	1381.41	2928.35	2301.10	3008.23
Prob > chi2	0.00	0.00	0.00	0.00
logL	-1413.13	-1316.69	-1289.09	-1300.15
df	15	15	15	15
AIC	2856.26	2636.38	2608.18	2630.31
BIC	2955.76	2761.26	2706.06	2728.33

*Abbreviations: AIC, Akaike's information criterion; BIC, Bayesian information criterion; df, degree of freedom; logL, log-likelihood function; N. obs., number of observations; SD, standard deviation; SE, standard error; LR chi2, Likelihood Ratio Chi-Square test. PU- Perceived Usefulness; EU-Ease of Use; OPT-Optimism; INN-Innovativeness; DIS-Discomfort; INS-Insecurity; PUxBT-interaction terms of PU & blockchain; EU*BT- interaction terms of EU & blockchain; OPT*BT- interaction terms of OPT & blockchain; INN- interaction terms of INN & blockchain; DIS*BT- interaction terms of PU & blockchain; INS*BT- interaction terms of INS & blockchain.*

*Note: ***, **, * significance, respectively, at 1%, 5%, and 10% levels.*

5.5 Discussion

This study is the first to explore US consumers' valuation of BT traceable shrimp and measure their WTP for these products. This study had four objectives. Firstly, the consumer preferences and WTP for BT traceable shrimp in the US were investigated. Results suggest that shrimp consumers are willing to pay premium prices for BT labels, QR codes, and no antibiotics labels over no labelled products. This was corroborated by Tran et al, (2024) who they explored ethnocentric dairy consumers who spent more time reading traceability information and registered a higher willingness to pay for BT-enabled traceability information. On the contrary, these outcomes were not aligned with another study on BT adoption in beef supply chains in the US where consumers valued USDA certifications over BT labels (Shew et al., 2021). It was found that the BT label was strongly preferred, with the highest value across all treatment groups. Moreover, the highest WTP ($4.16/lb) came from the respondents who read the information on the food safety benefits of BT followed by food fraud benefits with $3.61/lb respectively. Furthermore, consumers from the food fraud treatment group valued more with higher WTP for BT and QR code together, which outlines that they are interested in tracing the history of the shrimp using QR code and ensuring no fraudulent activities were noted till it points to sale. This outcome is corroborated by some studies that shared that Vietnamese consumers valued more utility to verify food fraud information for shrimp (Phong et al., 2023;Yin et al., 2022). Overall, consumers were worried by frequent news on seafood frauds and thus valued BT to retrieve trustworthy information to make a buying decision (Khan et al., 2022; Stirton, 2020).

On the other hand, food safety treatment group consumers found more utility in considering all labels together, i.e. BT, QR, and no antibiotics, which demonstrates consumers' fear associated with reasons such as news on banned antibiotics use in shrimp and restrictions on shrimps from major exporter viz. China, India, Thailand, Vietnam, and Ecuador in international markets such as the EU and the US (FDA, 2022), link shrimp as the most adulterated seafood (Lawrence et al., 2022), and common seafood fraud incidents (Cook, 2018; Dos Santos et al., 2021; Helyar et al., 2014; Howson, 2020; Khaksar et al., 2015). For this reason, the consumers from this group preferred the additional label of no antibiotics on shrimp to validate the food safety measures taken place during the production and throughout the journey of shrimp (Love et al., 2021;Yin et al., 2022). This is confirmed by Ortega et al., (2015) who emphasized that shrimp consumers valued transparency on food safety based on ‘no antibiotics’ and ‘country of origin’ labels.

Second, the effect of consumer characteristics on preference heterogeneity in WTP across consumers was examined. Consumer characteristics such as age, gender, income, education, hearing about BT, consumer trust and belief in the current shrimp supply chain, and transparency and belief in transparency in the current shrimp supply chain have shown significant effects on WTP. Meanwhile, in the food fraud treatment group, highly educated young people with children under 18 who had heard about BT before the study and who believed that trust and transparency are highly important in the shrimp supply chain showed higher WTP for BT traceable shrimp. This can be related to the young population being keener on food frauds in the seafood industry, and higher income groups especially are willing to pay premiums for benefits such as transparency and trust offered by BT, which is corroborated by Rao et al., (2023). Moreover, in the food safety treatment group, male consumers with higher income groups, although not heard about BT, and valued paying a premium for BT traceable shrimp products. These findings can be supported by studies such as Soley, (2016), and Wirth et al., (2007) which shows that higher-income groups are more likely to pay a premium for the credibility of information on food safety and seafood products.

Third, the effect of different communication messages about the benefits of BT on the WTP of shrimp was tested. A noticeable effect of information communication messages about BT benefits was noted resulting in higher WTP for BT-enabled shrimps as compared to the control treatment group. Thus, consumers who read the information on the benefits of BT showed higher WTP compared to no information group except the sustainability benefit treatment group. This was in line with several other studies that showed similar results on the positive effect of communication messages against no information provides (Asioli et al., 2021; Koemle & Yu, 2020; Ortega et al., 2014, 2015). Meanwhile, the communication message with food fraud benefits of BT gathered the highest utility with premium WTP across treatments. As discussed earlier, this was corroborated by other similar studies Phong et al., (2023); Yin et al., (2022) and it was reasoned with the fear of consumers based on the increase in fraudulent incidents in the news.

Fourth, it was investigated whether US shrimp consumers are ready to accept BT traceable shrimp. Overall, the results of consumers showed acceptance and readiness for BT. The results gained from the TRAM model were interesting, as two constructs of TAM (Perceived

Usefulness and Perceived Ease of Use) and two constructs of TRI, such as optimism and innovativeness, showed a positive and significant relation with higher WTP. Whereas the other two constructs of TRI also called as contributors such as insecurity and discomfort showed negative and significant relation with the consumer WTP, and corroborated by Kampa, (2023). Thus, these six constructs extracted from TAM and TRI have contributed to the acceptance and readiness by consumers for the use of BT in the SSC by valuing the benefits of BT they read to make informed decisions when buying shrimp with higher importance for trust and transparency. Thus, consumers would show a positive response to accepting BT traceable shrimp, based on the credibility of information, with enhanced trust and transparency. These results are confirmed by other studies (Lin et al., 2021; Durach et al., 2020; Esfahbodi et al., 2022; Jariyapan et al., 2022; Queiroz & Wamba, 2019; Shrestha et al., 2021; Shrestha & Vassileva, 2019; Wong et al., 2020).

5.5.1 Implications for businesses and policymakers

This study provides several relevant implications and recommendations for shrimp businesses and retailers. First, based on the results found, shrimp processing companies aiming to enhance consumer trust and transparency in their supply chains must consider using BT as a tool to strengthen consumer confidence. From the results, consumers show a preference for BT traceable shrimps thus companies could consider investing in and promoting BT as a means of providing verifiable information about the origin, production, and handling of their shrimp products, which can address concerns related to food fraud, food safety and ethical sourcing.

Second, in terms of marketing strategies, businesses can consider the findings of this study to develop effective marketing strategies highlighting the benefits of BT traceability. Consumers have shown perceived value for labels such as BT, No Antibiotics Ever, and QR codes with higher willingness to pay for shrimp products with these labels. Thus, businesses can incorporate this information into their marketing materials and product labelling. Thus, BT can become a unique selling point, allowing companies to differentiate their products in a competitive market and potentially command premium prices.

Third, shrimp businesses and retailers can take advantage of optimizing their supply chain processes and inventory management using BT, which would enable them to form a more efficient and resilient seafood supply chain. Moreover, BT has the potential to trace products at every stage of the supply chain, which would assist businesses in risk mitigation with quick identification of any issues, such as contamination or fraud, and food safety issues, thus safeguarding the company's reputation.

Fourth, these findings are highly relevant for designing policies on SSC traceability using BT that contribute to fostering transparency and trust in the overall supply chain operations (ByteAlly, 2019; Khan et al., 2022; Vu et al., 2022). This study further suggests the use of QR codes along with BT labels as valued by consumers to help them read authentic information about the production practices, journey of product ownership throughout the supply chain, and certifications involved to ensure food safety (Ding et al., 2022; Khan et al., 2022). Furthermore, policymakers might want to consider the positive sign of consumer acceptance and readiness of consumers for BT traceable shrimps suggested by this study to futureproof the upcoming demand from consumers on verifying the credibility of labels on shrimp products and the processes. Since the majority of shrimp in the US is imported from developing nations and thus to enhance food safety and reduce food frauds, policymakers might consider building a regulatory framework that supports BT adoption in SSC, which includes creating incentives for businesses to encourage smooth adoption(Aya et al., 2021; FDA, 2022; Okocha et al., 2018).

5.5.2 Future Research Directions

Several further research possibilities emerge from this study. First, future researchers may consider investigating the inclusion of new or additional attributes related to shrimp products, which would include packaging, processing methods, specific production practices, or the use of other complementary technologies along with BT, such as IoT codes (Islam et al., 2022). Assessing the relative importance of these attributes can provide a more comprehensive understanding of consumer preferences. Second, it can be explored how consumer preferences and WTP may change over time for BT traceable shrimps by conducting longitudinal studies to capture shifts in consumer attitudes towards shrimp products and how external factors, such as changes in environmental awareness or economic conditions, may influence valuation.

5.5.3 Evaluating the Worst-Best Range of Willingness to Pay (WTP) with Status Quo Considerations and realism of the experimental design

A Best-Worst WTP Analysis is conducted using data from Tables 11, 12, and 13, with particular focus on BT attributes and incorporating the Status Quo (SQ) as the baseline. This approach allows for a critical examination of whether the WTP estimates align with realistic consumer behaviour in real-life purchasing contexts.

Best-Worst WTP Ranges with SQ as Baseline

The SQ option which reflects a scenario where consumers prefer the default choice over blockchain-enabled shrimp traceability including this as the **worst-case value** reveals significant differences in WTP across scenarios:

- **Based on the Main Effects Table 11:**
    - Maximum WTP for blockchain: **$4.16/lb**
    - SQ (worst-case):**−10.90/lb**
- **Range:** 4.16−(−10.90)=**15.06/lb**

- **Baased on the Interaction Effects Table 12:**
    - Maximum WTP for blockchain: **$9.98/lb**
    - SQ (worst-case): **−11.34/lb**
- **Range:** 9.98−(−11.34)=**21.32/lb**
- **Consumer Characteristics Table:**
    - Maximum WTP for blockchain: **−0.82/lb**
    - SQ (worst-case): **−11.33/lb**
    - **Range:** −0.82−(−11.33) = **10.51/lb**

Analysis and Interpretation

1. **Wide WTP Ranges and their Implications:**

The calculated ranges reveal that WTP estimates for BT-enabled traceability vary significantly, particularly in the **Interaction Effects Table**, where the range is **$21.32/lb**. Such wide variations highlight the hypothetical nature of stated choice experiments (SCEs), where respondents may express stronger preferences compared to real-life situations. This discrepancy aligns with existing research on **hypothetical bias** in stated preference studies (Lusk & Schroeder, 2004). Consumers, when not spending actual money, may overstate their willingness to pay for attributes like blockchain traceability, particularly for emerging technologies that are not yet familiar or tangible in their daily purchasing decisions. The magnitude of the WTP estimates ranging from $12.14/lb (main effects) to $21.32/lb (interaction effects) raises questions about their alignment with realistic consumer behavior. These values, when added to existing product prices, suggest a significant premium for BT-traced shrimp, which could be perceived as excessive in real-world market scenarios.

2. **Realism of WTP Estimates:**

Integrating the SQ option underscores that BT-traceable products are not thoroughly preferred. A significant amount of respondents still value the default choice (SQ) overpaying a premium for BT-based attributes. This finding reflects market resistance often encountered in the early stages of technological diffusion (Rogers, 2003), particularly in price-sensitive segments such as seafood consumers. For example, in Table 13 (Consumer Characteristics), BT's maximum WTP is negative (−0.82/lb), suggesting that certain demographic groups perceive BT traceable shrimp as less valuable or unnecessary. The critical evaluation of the experimental design further emphasizes the importance of aligning WTP estimates with real-world market conditions. For instance, the variability observed in WTP across different contexts ranging from $9.59/lb (consumer characteristics table) to higher premiums in interaction effects demonstrates that blockchain traceability's perceived value is not universally high. This variability reflects differing consumer priorities, such as food safety, transparency, and ethical sourcing of shrimp, as well as the challenges by accurately capturing these preferences through hypothetical scenarios.

3. Experimental Design Consideration:

To enhance the realism and applicability of these findings, the study recommends integrating Real Choice Experiments (RCEs) or experimental auctions, where actual financial stakes are involved. Such methods could validate whether consumers are truly willing to pay the premiums suggested in the DCE results. Moreover, field experiments in retail settings, where BT-labelled shrimp are presented alongside conventional products, could provide valuable insights into consumer behaviour under realistic purchase conditions. Thus, this approach would help validate the high WTP values observed in this study. By including the SQ as a baseline in the Best-Worst WTP Analysis provides a more refined understanding of consumer preferences for

BT-traceable shrimps. While the wide ranges observed in this study highlight the potential for overstated preferences in hypothetical scenarios, they also reveal critical insights into consumer behaviour. Thus, future studies can combine stated preference methods with real-choice validation to strengthen the realism of WTP estimates, providing more actionable insights for industry stakeholders and policymakers.

5.6 Conclusion

This study contributes to addressing the current knowledge gap on consumer preference for BT traceable shrimp by using a large sample set. This is the first empirical study to investigate consumer valuation of BT traceable shrimp in the US. It further explores the valuation of BT across different shrimp consumer segments and attempts to provide information on the acceptance and readiness of BT traceable shrimps. Several studies have investigated consumer preferences for shrimp; however, the majority of them explored the consumer valuation of sustainability or eco-labels, such as organic certifications or traceability labels on the origin of shrimp products (Ortega et al., 2014, 2015; Wirth, 2014; Soley, 2016; Yin *et al*., 2020; Phong et al., 2023). Overall, the results show that consumers valued BT labels with higher WTP ($4.16/lb). Heterogeneity was observed in the valuation by consumers from different treatment groups, where food safety treatment groups noted the highest WTP for BT traceable shrimps. Furthermore, it was seen that young consumers from high-income groups and children under 18 in households showed high WTP for BT traceable shrimps. Moreover, a significant effect of information provision (benefits of BT) on higher WTP against no information was noted. Lastly, consumers have shown a positive sign of acceptance and readiness for BT.

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CHAPTER 6: General Discussion and Conclusion

6.1 General discussion

This thesis aimed to explore the SSC) stakeholders views on BT adoption and investigate consumer preferences for BT traceable shrimps. We specifically aimed for three objectives viz. i) to examine the existing literature and identify the benefits and costs of BT adoption in the AFSC, ii) to explore in-depth expectations, and opinions of ISSC stakeholders on BT adoption, and iii) to investigate the US consumers' preferences for BT traceable shrimp.

6.1.1 Literature review

First, a comprehensive range of BT literature across agriculture, food, and fisheries was reviewed using narrative review accompanied by PRISMA to understand the current development in academic research on BT with special attention to fisheries and aquaculture supply chain (FASC). The results showed that BT has gained more popularity in academic research with a surge in the number of academic publications over the last seven years only due to its promising potential to address key challenges related to AFSC which includes traceability, transparency, and sustainability as confirmed by various other studies (Adamashvili et al., 2021; Madumidha et al., 2019; Park & Li, 2021; Sander et al., 2018; Tayal et al., 2021). Moreover, China, India, and Italy were the top three countries researching the topic respectively. It was found that the decentralised and distributed nature of BT offers immutability of data stored on it and shares the credibility of the information shared among stakeholders and consumers, thus enhancing trust throughout the supply chain (Akella et al., 2023; Bandinelli et al., 2023) . Thus, BT assures good coordination among stakeholders with enhanced visibility and traceability due to real-time monitoring, which further offers easy detection of food frauds and builds consumers' confidence in brand building, as corroborated by other studies (Callinan et al., 2022; Olsen et al., 2022) . We found that in the reviewed existing body of literature the majority of studies focused on two types of articles viz. review articles that only presented a literature review of the implementation of BT in AFSC and FASC (Dey & Shekhawat, 2021; Luna et al., 2023; Patro et al., 2022; Pournader et al., 2020; Rampone et al., 2023; Xu et al., 2019), and the articles those focused on the development of a theoretical framework or models for BT implementation in AFSC (including FASC) (Khan et al., 2022; Luna et al., 2023; Patro et al., 2022; Rampone et al., 2023). This highlighted a huge gap and paucity of empirical research on the practical adoption of BT in AFSC.

Similarly, several articles highlighted the suitability of BT into FASC due to its decentralised features of data sharing among stakeholders (Patro et al., 2022; Yin et al., 2022) enhancing high production standards, restricting contamination and wide visibility throughout the AFSC (Aung

& Chang, 2014; Khan et al., 2022). Furthermore, the important benefits of BT in FASC highlighted were about significant reduction of food safety concerns such as the use of banned antibiotics as corroborated by other studies (Aya et al., 2021; Ortega et al., 2014, 2015) , and check on fraudulent activities as explained by some studies (Cook, 2018; Dos Santos et al., 2021; Helyar et al., 2014; Howson, 2020). However, most of the articles on FASC too focused on conceptual frameworks of BT implementation and an overall lack of empirical research such as primary research with stakeholders' perceptions to study their opinions and thoughts on BT adoption was noted, as corroborated by studies (Førsvoll & Åndal, 2019; Tsolakis et al., 2021). Furthermore, it was observed that shrimp is the world’s top traded and consumed seafood product accounting for approximately 15% of global seafood sales (FAO, 2021b) and is associated with the most reports of seafood adulteration (Lawrence et al., 2022). But despite such importance in global trade, shrimp supply chains are hardly explored in terms of the existing challenges and use of technology adoption to solve them. Therefore, this highlights another vast void in literature to be explored. Furthermore, we found that although India is one of the top exporters of shrimp globally there is a notable gap in empirical evidence of BT adoption in the Indian shrimp supply chain (ISSC) on its ongoing challenges and their prospective solutions using emerging technologies such as BT as corroborated by some studies such as(Holger et al., 2020; Juditstarlin & Jothi, 2021; Salunke et al., 2020).

We further identified the benefits and costs from the literature and grouped them based on their categories as supply chain benefits, market benefits, risk and recall benefits, food safety and quality benefits, and regulatory benefits; and costs such as implementation and operations costs. Thus, this laid motivation to explore and investigate BT adoption in ISSC. Thus, these outcomes on benefits and costs from the literature reviewed were used to develop questionnaires for the next studies.

6.1.2 Stakeholder perceptions on BT adoption in the Indian shrimp sector

Secondly, we addressed the second objective in chapter four. The research focused on the FASC and specifically ISSC was inspired by a variety of reasons: i) significant increase in demand for shrimp globally; ii) lack of empirical studies on stakeholders' perception exploring current challenges and potential solutions using emerging technologies e.g. BT; iii) rise in global concerns over provenance and authenticity of shrimp mainly in terms of food safety, quality, and fraud; iv) lack of empirical studies on Indian shrimp sector despite one of the top shrimp producers and exporters in the world. Thus, this is the first study to explore ISSC stakeholders' perceptions and opinions on BT adoption. We found that the ISSC stakeholders shared a positive impression of BT as a solution to their existing pain points in the sector. The stakeholders have recognized the numerous benefits of BT in ISSC. By adopting BT, all stakeholders can be brought together on a single platform, which improves coordination, visibility, and trust among them. These findings are supported by several studies such as Liu et al., (2020); Prashar et al., (2020a); Rogerson & Parry, (2020); Singh & Sharma, (2023); Yang et al., (2021); Zheng et al., (2023). Furthermore, the other crucial benefits of BT for the FASC sector highlighted were reduced dependency on middlemen, and the building of consumer trust by providing them with verifiable and credible information about the origin, production, and handling of shrimp through end-to-end visibility offered. These findings are corroborated by findings from Singh & Sharma, (2023). On the contrary, surprisingly stakeholders shared a common consent on the fact that BT being a new technology would have initial higher costs (i.e. the implementation and operations cost) incurred which would eventually go down as the technology matures. This finding is not confirmed prior by any study and thus is one of the key findings.

Several findings from the literature review on the challenges in the seafood sector matched the findings of this study where the most significant issue mentioned by stakeholders in ISSC was the occurrence of diseases, such as white spot syndrome and running mortality syndrome (RMS), which adversely affect shrimp production. This, in turn, leads to price fluctuations, causing significant financial losses to all stakeholders, especially farmers (Alavandi et al., 2019; Srinivas et al., 2016). Additionally, the lack of transparency and traceability in ISSC remains a significant challenge, leading to a lack of coordination and trust among stakeholders which was a concern that has been raised in several contemporary studies on BT adoption (Holger et al., 2020; Srinivas & Venkatrayalu, 2016).

A further important issue raised was, about middlemen taking a major portion of the profit due to poor transparency which was supported by other similar studies Kimani et al., (2020); Kittipanya-ngam & Tan, (2020); Motiwala et al., (2021a). The findings that lack of transparency further creates opportunities for fraudulent activities like mixing certified and non-certified shrimp for sale as certified, resulting in greater profits was not found in other studies and is a unique finding that sets this study apart from others. Meanwhile, stakeholders remain concerned about the use of antibiotics and restrictions on Indian shrimp in international markets, such as the EU and the US (FDA, 2022), which is due to a lack of education and training for farmers by the government. Finally, several processors and exporters expressed dissatisfaction with long waiting times for products at foreign ports, which increases transportation costs and further reduces margins - a concern that has also been confirmed by previous studies (Altuntaş Vural et al., 2020; Clapano et al., 2022).

On the contrary, the majority of stakeholders suggested farmers' training on new practices of farming leaving behind the traditional way of shrimp farming such as not compromising the quality of seeds/broodstocks which makes production vulnerable to diseases (Holger Rubel et al., 2020; Sivaraman et al., 2019; Ulhaq et al., 2022). Furthermore, a common voice on the use of novel technology which would provide a single shared platform for all stakeholders and enhance transparency and trust among them by significantly reducing the dependency on middlemen was a key highlight. This finding too is not corroborated by any other study. Similarly, the enhanced traceability would enable a reduction in frauds or perhaps early detection of them due to real-time data availability in BT. A study by Tanger et al., (2019) seconded these findings on the regulatory benefit of BT. In terms of benefits and costs majority of stakeholders shared a common interest in adopting BT due to the enhanced transparency, traceability and trust offered which results in better coordination and builds consumer confidence which is a key driver of shrimp exports in India. These findings were in line with Cao et al., (2021) who shared that the use of BT in food supply chains increases consumer trust due to the integration of the self-governance mechanisms of BT. Additionally, in line with findings by Adamashvili et al., (2021) that it is easier to trace back the food origin in a food recall situation due to the real-time data capture and visibility in SSC by BT, where similar opinion was shared by several stakeholders for shrimp. Moreover, as per the majority of ISSC stakeholders, as BT is a fairly new technology, they expect some initial costs involved however they would decrease as the technology matures (Bumblauskas et al., 2020; Jabbar & Dani, 2020; Olsen et al., 2019; Venkatesh et al., 2020). This finding contradicts other studies by Asif et al., (2021); and Jabbar & Dani, (2020) on rejection of BT adoption compared to other attributes.

6.1.3 Consumer study on BT-certified shrimp and willingness-to-pay

Third, chapter 5 addressed the third objective of the thesis using a discrete choice experiment that aimed to investigate American consumers' preferences for BT-traceable and measure their willingness to pay (WTP). This study contributed to addressing the current knowledge gap on consumer preference for BT traceable shrimp and thus is the first empirical study to investigate consumer valuation of BT traceable shrimp in the US. The results showcased that the consumers are willing to pay a premium for shrimp with BT labels, QR codes, and no antibiotics labels compared to unlabelled products which was in line with a study by (Tran et al., 2024). Consumers were divided into four treatment groups based on the different information messages on the benefits of BT, and it was found that consumers who read information on food safety benefits of BT had the highest WTP of $4.16/lb, followed by those who read about food fraud benefits with $3.61/lb. Moreover, it was worth noting that the consumers from the food fraud treatment group demonstrated a significantly higher willingness to pay for both BT and QR labels together. This strongly indicated their preference for utilizing QR codes to trace back the origin of shrimp and ensure that no fraudulent activities have occurred in the supply chain. These findings were supported by a study on shrimp with Vietnamese consumers who value the ability to verify information about food fraud in shrimp as a top priority (Phong et al., 2023; Yin et al., 2022). These results also underline the fact that consumers encounter frequent news on seafood frauds, resulting in valuing BT to get true information on the history of shrimp when buying (Khan et al., 2022; Stirton, 2020). On the contrary, consumers from food safety treatment noted more utility in considering all three labels together i.e. BT, QR, and no antibiotics, which exhibits consumer concerns linked to news on the identification of banned antibiotics shrimp in the US or EU from the top shrimp producers viz. China, India, Ecuador, Vietnam, etc. (FDA, 2022). Thus, consumers valued additional no-antibiotic labels to get assured of the food safety measures taking place during the journey to the point of sale. This is confirmed by Ortega et al., (2015) who stressed that shrimp consumers valued transparency on food safety based on 'no antibiotics' and 'country of origin' labels.

We further examined the effect of consumer characteristics on preference heterogeneity in WTP across consumers. Results showed that the WTP is significantly influenced by consumer characteristics such as age, gender, income, education, BT awareness, trust and belief in the current shrimp supply chain, and transparency. Specifically, young consumers from higher income groups are seen to be keener on food frauds in the seafood industry and thus are willing to pay premiums for benefits offered by BT on transparency and trust which is corroborated by Rao et al., (2023), and Strebinger & Treiblmaier, (2022).

The study examined how different messages about the benefits of BT impacted consumers' willingness to pay for shrimp. Results showed that providing information about BT benefits led to higher WTP for BT-enabled shrimp compared to the control group. Consumers who received this information showed higher WTP than those who received no information, except for the sustainability benefit group. This was in line with similar studies that have also shown positive effects of communication messages compared to no information (Asioli et al., 2021; Koemle & Yu, 2020; Ortega et al., 2014, 2015). BT's communication message regarding food safety benefits received the highest utility with premium willingness-to-pay across treatments. As discussed earlier this was corroborated by other similar studies (Phong et al., 2023; Yin et al., 2022) and reasoned with fear of consumers based on the increase in fraudulent incidents in the news.

Lastly, we investigated the acceptance and readiness of American shrimp consumers for BT. Overall, the results indicate that consumers have shown acceptance of and readiness for BT. The results obtained from the TRAM model were quite fascinating. The analysis demonstrated that two components of TAM, specifically Perceived Usefulness and Perceived Ease of Use, along with two components of TRI, namely optimism and innovativeness, showed a noteworthy and positive correlation with increased WTP. In contrast, the remaining two components of TRI, recognized as contributors, specifically insecurity and discomfort, displayed a negative significant correlation with WTP which was as expected and supported by other studies (Kampa, 2023).

6.2 Implications and recommendations for businesses and policymakers

This study provides several important implications and recommendations for shrimp businesses and policymakers in India.

6.2.1 Businesses

First and foremost, businesses from ISSC must give careful consideration to the findings of this study, particularly about the willingness of American consumers to pay a premium for BT traceable shrimp. Thus, businesses must start building their marketing strategies to use BT as a unique selling point and to differentiate their shrimp product to capture higher market share.

Second, the results from the effect of information across treatment groups highlighted premium WTP by consumers who read food fraud and food safety benefits of BT compared to those who read no information. These findings could be used to build product promotion strategies that focus on shrimp products free from fraud and antibiotics. This can be accomplished by introducing QR code labels, which provide access to information on product origin, production techniques, procedures, sustainability standards, and other relevant data. Such labels would enable consumers to verify the product's authenticity and make informed purchasing decisions (Gephart et al., 2019). These initiatives would build back consumer trust in the brands and overall supply chain operation and thus businesses must consider using BT as a tool to strengthen consumer confidence for brand loyalty.

Third, a positive interest from ISSC stakeholders who acknowledged the benefits and costs of BT adoption must be considered to adopt a BT-enabled traceability system for ISSC. Businesses must prioritise implementing a BT-enabled single platform for all to address various existing challenges such as stakeholder coordination issues, lack of trust, lack of operational efficiency due to lack of visibility, and importantly issue of middlemen. BT would serve as a single source of truth enabling effortless coordination, communication, and reliable data sharing with end-to-end visibility and transparency reducing reliance on middlemen to boost profit margins. BT would help businesses to make faster business decisions based on real-time and authentic data availability.

Lastly, businesses must start investing in capacity building with the allocation of sources for BT adoption and training employees on the benefits and use of technology for efficient operations, and for smooth integration with existing systems.

6.2.2 Policymakers

First, policymakers must acknowledge the positive interest from both ISSC business stakeholders and consumers in BT adoption in the sector. This showcases a good opportunity for policymakers to revolutionize the ISSC sector by bringing the whole fragmented and complex Indian shrimp sector together on a single platform by introducing transparency and trust in the day-to-day business operations.

Second, policymakers must prioritize the integration of BT in ISSC by building a regulatory framework to adopt BT recognizing its potential to enhance accountability and transparency in the shrimp industry. BT enables the industry to uphold ethical standards, discourage fraudulent activities, and ultimately create a more sustainable and trustworthy shrimp industry, thus as a result building trust among the importers, regulatory bodies, and the end consumers.

Third, policymakers must create mandatory training to educate fishers/farmers on modern farm practices to learn how to handle diseases and how to avoid the use of antibiotics. The government policies must consider raising awareness of BT benefits and costs to promote easy adoption with provisions of incentives.

Fourth, policymakers should engage in international collaborations to establish global standards for BT-enabled supply chains and participate in discussions to standardize regulations and facilitate cross-border shrimp trade by leveraging the end-end visibility and real-time immutable data availability on quality and standards of the product.

Fifth, policymakers should encourage the widespread adoption of BT by showcasing successful case studies in other sectors and advocating for policies that promote BT adoption.

Lastly, to motivate smooth BT adoption in ISSC, policymakers must provide financial support to businesses such as incentives through tax cuts or grants. Stakeholders specifically shrimp farmers/fishers must be given incentives for smooth BT adoption. This framework will serve both domestic and international demand for shrimp, thereby enhancing the export potential of Indian shrimp.

6.3 Future research

Several future research directions can be provided based on this study's results. First, considering the increasing interest among stakeholders and consumers a longitudinal study could be recommended to track the BT adoption progress in ISSC over an extended period. Researchers could explore shifts in stakeholders' perceptions, and BT adoption challenges in the sector. In Addition, a sample-based longitudinal discrete choice experiment similar to a study by Keller et al., (2021) to investigate changes in consumer attitudes and preferences for WTP for BT traceable shrimps, could be conducted.

Second, a separate study on the technical challenges related to the integration of BT with existing systems, on interoperability, scalability, or data standardisation could be recommended in ISSC.

Third, to assess the successful BT adoption in ISSC, a large number of case studies on BT adoption in ISSC would be highly recommended in the future to identify critical success factors, lessons learned, and best practices in the sector to guide stakeholders, researchers, and policymakers.

Fourth, due to the void in the literature on the topic, and second the findings from this thesis, we recommend other supporting studies to provide evidence to accurately measure the depth and precision of adaptability of BT-enabled traceability in ISSC.

Fifth, a CE study with a combination of different attributes e.g. sustainability labels, and the effect of consumer characteristics in addition to age, gender, income, and education such as ethnicity, technology adaptation behaviors, profession, etc. may result in different or even precise utility maximisation in the future.

Sixth, there is a need for further detailed research to build a BT adoption framework for ISSC that would adapt the existing shrimp supply and value chain business model.

Seventh, researchers could study the influence of BT adoption in ISSC on stakeholders' day-to-day operations e.g. the effect of the use of smart contracts for automated transactions for real-time settlement of payments and explore its impact on profit margins of all stakeholders.

6.4 Limitations of the study

The following are some limitations of both the studies from this thesis identified:

First, the sample for the qualitative study on stakeholder perception was limited to 23 stakeholders from the overall ISSC which cannot be expanded to all stakeholders from the sector and thus has only a qualitative value. Moreover, among these 23 only a small number of individual categorical representations could be possible such as 4 respondents from the pre-production stage (feed companies and shrimp hatcheries), 7 from the production stage (farmers/fishers), and 12 from the post-production stage (traders, processors, exporters, importers).

Second, the CE study was a hypothetical study where we did not monitor the actual behavior of consumers in a real-world situation. It is worth noticing that when consumers are faced with tangible choices and market conditions, they may respond differently in actual purchasing behavior compared to hypothetical situations.

Third, the qualitative study was conducted with only stakeholders from India, and the findings from this study might not be generalisable to other regions. Future research must explore a comparative study on BT adoption in the shrimp supply chain in other regions to obtain a more comprehensive understanding of this domain.

6.5 Critical commentary on various aspects of study

6.5.1 Choice of Approach and Methodology

The thesis employed a mixed-methods approach, combining qualitative semi-structured interviews and a quantitative discrete choice experiment (DCE) to thoroghly explore the adoption of BT in the Indian FASC. This methodological design was carefully chosen to provide both exploratory and explanatory insights in a scarcely explored and under-researched field of BT adoption in FASC. The qualitative phase aimed to capture stakeholder perspectives including producers, processors, and regulators on the perceived benefits, challenges, and adoption barriers of BT. By achieving thematic saturation, this phase ensured validity and allowed for the development of a robust framework that informed the quantitative phase (Guest et al., 2006). The DCE, a widely used stated preference method, measured consumer preferences and WTP for BT-traceable shrimp products. Its strength lies in simulating realistic trade-offs between attributes, offering insights into how consumers prioritize traceability, transparency, and sustainability in their purchasing decisions (Hensher et al., 2015).

While this mixed-methods approach provided strong and actionable insights, a critical perspective highlights certain limitations too. The qualitative phase, for example, showcased a potential self-selection bias, where participants with positive views on BT adoption were more likely to engage in the study. Although the sample included diverse staekholders across the supply chain, additional methods such as the Delphi technique could have addressed this limitation by iteratively involving a broader range of experts, facilitating consensus on critical issues (Okoli & Pawlowski, 2004). Similarly, the DCE, although robust, is prone to hypothetical bias, where participants may overstate their preferences in an experimental setting compared to real-world behaviours (Lusk & Schroeder, 2004). To improve external validity, future research could employ Real Choice Experiments (RCEs) or field trials to validate stated preferences against observed purchasing behaviours, to enhance the reliability of WTP estimates (Lusk & Shogren, 2007; Hess & Daly, 2014).

In terms of real-life applications, the findings of this study provide actionable insights for stakeholders across the FASC, especially in the Indian context who are the top exporter of shrimp to the top markets such as the US. The WTP identified from the study for BT-traced shrimp underscores the value of targeting premium export markets, particularly in regions such as the U.S. and the EU, which have stringent traceability and food safety regulations (Rao et al., 2023; Yang et al., 2024). Furthermore, qualitative insights emphasized the need for policy interventions, such as government subsidies or financial incentives, to facilitate BT adoption among small and medium-sized enterprises (SMEs), which constitute the majority of the shrimp sector in India (Kumar et al., 2022). Furthermore, the findings suggest that BT implementation can streamline supply chain processes, reduce fraud, and build consumer trust, especially when combined with technologies like IoT for real-time monitoring and data verification (Jiang et al., 2023; Acciarini et al., 2023).

By critically evaluating the methodological choices and their implications, the thesis ensures a balanced perspective that combines academic rigour with practical relevance. This discussion not only addresses the academic research gap in BT adoption but also outlines a clear pathway for its real-world application in fisheries and aquaculture supply chains, offering a valuable resource for policymakers, industry stakeholders, and technology providers.

6.5.2 Motivating Farmers to adopt BT with Incentives

Educating farmers about BT is a necessary but inadequate step to support widespread adoption. In the context of the Indian shrimp industry, where SMEs dominate production, substantial incentives beyond educational awareness are essential for smoother adoption of BT. A critical perspective reveals that financial, operational, and market-based incentives are among the most effective motivators for farmers to integrate BT into their practices.

Financial Incentives for BT Adoption

One of the primary barriers to BT adoption in the shrimp sector is its high upfront implementation costs, which include infrastructure, training, and data management systems (Kumar et al., 2022). Farmers, particularly small land-holders, often operate on low profit margins and are unlikely to invest in BT like technologies without financial support. Subsidies or grants from government bodies or international organizations could significantly lower the entry barrier. For example, targeted subsidies tied to sustainability or traceability improvements could support with export market requirements in regions such as the U.S. and the EU, where compliance with rigorous traceability standards is required (Rao et al., 2023). Tax incentives for BT-enabled supply chains may also encourage processors and exporters to adopt the technology, creating a ‘trickle-down’ effect for farmers.

Market-based incentives

Moreover, another critical motivator is the market access. Farmers who adopt BT can position themselves as premium suppliers in global markets, securing long-term contracts with international stakeholders such as retailers and food service companies (Yang et al., 2024). BT-enabled traceability systems would improve transparency and compliance, giving Indian shrimp a competitive edge against products from other exporting nations like Vietnam and Ecuador, which are also exploring BT adoption (Nakamura et al., 2022). Additionally, certifications linked to BT implementation could allow farmers to charge premium prices, increasing their revenue and offsetting the costs associated with adopting the technology.

Operational Incentives and Risk Mitigation

Operational efficiencies gained through BT adoption could also serve as an incentive for farmers and other stakeholders in the FASC. Trough automating processes such as record-keeping, compliance documentation, and payment settlements via the smart contracts feature of BT would reduce administrative burdens and associated costs (Jiang et al., 2023). Moreover, BT enhances transparency, which can help farmers build trust with downstream buyers, potentially reducing disputes and payment delays. These operational benefits give farmers a practical reason to adopt BT beyond theoretical advantages.

Role of Co-operative based model

Considering the fragmented nature of the Indian shrimp industry, individual farmers may lack the resources or scale to adopt BT independently. Cooperatives or cluster-based models could be explored as a good option to distribute costs and benefits across a network of farmers. By sharing resources, smallholders could share the costs of BT adoption, such as the deploying IoT devices for real-time data entry, while collectively benefiting from improved traceability and market access. This collective approach aligns with prior research emphasizing the role of shared resources in overcoming technological barriers in agriculture (Balaji et al., 2021).

Critical Challenges and Future Directions

Despite these potential incentives, challenges such as a lack of digital literacy, scepticism about technological innovations, and resistance to change must be acknowledged. Efforts to motivate farmers should, thus must include capacity-building initiatives to develop digital skills and demonstrate the tangible benefits of BT adoption. Future research could explore behavioral economics approaches, such as incentive design tailored to farmer preferences, or randomized controlled trials to identify the most effective motivational strategies. By addressing these critical dimensions, this discussion acknowledges that education alone cannot drive BT adoption among farmers but a multi-faceted approach combining financial, operational, and market-based incentives, alongside collective action frameworks, can create a sustainable ecosystem for BT implementation in the Indian shrimp industry.

6.5.3 Enhancing Transparency and Trust with BT-Enabled QR Codes

Consumer uncertainty regarding food safety, shrimp sourcing practices, and supply chain integrity remains a major barrier for Indian shrimp exporters. Challenges including fraudulent labelling and contamination risks, have damaged trust in the industry (Jiang et al., 2023). BT-enabled QR codes offer a scalable and efficient solution to these challenges, allowing consumers to access verifiable, real-time product information via their smartphones. This technology bridges the trust gap between suppliers and end consumers by enhancing transparency in the shrimp supply chain (Acciarini et al., 2023). QR codes serve as an easily accessible tool of credibility, showcasing traceability details such as origin, farming practices, and certifications, thereby addressing key consumer concerns.

Consumer Engagement with BT-Enabled QR Codes

Urban and highly educated consumers, particularly in export markets such as the U.S., EU, and Japan, are more likely to engage with QR codes as part of their purchasing decisions. These consumers often prioritize food safety, ethical sourcing, and sustainability, making QR code-enabled traceability systems a critical factor in fostering brand loyalty (Kim et al., 2022). However, the domestic adoption of QR codes in rural and semi-urban Indian markets may face challenges due to limited awareness and technological accessibility. To maximize the potential of QR-based BT systems, consumer education campaigns are essential. These initiatives should aim to simplify the interpretation of QR-based traceability information, increasing trust and enabling more informed decision-making across diverse demographics.

Implications of Industry-Wide QR Code Implementation

If BT-enabled QR codes became widely adopted across India's shrimp sector, the impact would extend beyond individual exporters to reshape the industry as a whole:

1. **Consumer Trust and Market Differentiation**: QR codes would significantly improve consumer confidence in Indian shrimp by addressing concerns about fraudulent labelling and supply chain complexity. In international markets, BT-enabled traceability would serve as a competitive differentiator, helping Indian stakeholders especially exporters meet stringent food safety and sustainability regulations while reinforcing their reputation as trusted suppliers (Nakamura et al., 2022).

2. **Supporting Small-Scale Farmers**: Large-scale exporters may find it easier to integrate BT, but small-scale shrimp farmers could struggle with compliance and implementation costs. Government support through financial incentives, technology grants, and cooperative

blockchain networks would be crucial for democratizing access and ensuring that smaller players benefit from industry-wide improvements in traceability (Galvez et al., 2018).

3. **Regulatory Impacts**: Widespread adoption of QR-based BT systems could drive regulatory evolution, resulting in mandatory traceability standards affiliated to electronic traceability laws in the EU and the FDA's traceability rule in the U.S. (Nandi et al., 2021). This shift could establish India as a global leader in traceable shrimp exports, enhancing its market share in premium seafood markets.

6.5.4 What If BT adoption became a standard in the Indian Shrimp Industry?

If BT traceability were to become a standard requirement in the Indian shrimp sector, it would likely transform the industry's operational landscape:

1. **Increased Consumer Confidence**: Widespread BT adoption would alleviate consumer concerns about seafood fraud and contamination, strengthening trust in Indian shrimp products (Gao et al., 2021). This trust would not only boost demand but also allow exporters to fetch premium prices in competitive global markets.

2. **Operational Challenges for Small Farmers**: Small-scale producers could face challenges in meeting the technological and financial requirements of BT implementation. Government initiatives, such as subsidized technology adoption programs and capacity-building workshops, would be essential to bridge this gap and enable inclusive participation in the BT-enabled ecosystem.

3. **Regulatory Framework**: A standardized approach to BT traceability could prompt the Indian government to introduce regulations ensuring industry-wide compliance. Such regulations would align Indian shrimp exports with global standards, enabling smoother

market access to regions with strict traceability mandates, such as the U.S. and EU (Nakamura et al., 2022).

Therefore, BT-enabled QR codes hold immense potential to enhance transparency and trust in the ISSC, in both domestic and international markets. Their adoption, however, requires coordinated efforts across stakeholders, including exporters, processors, farmers, and policymakers. By addressing challenges such as cost, consumer education, and technological integration, India can not only meet global market demands but also solidify its position as a leader in sustainable and traceable seafood production.

The Role of Exporters and Retailers in BT Adoption

Indian shrimp exporters, including industry leaders such as Devi Seafoods, Falcon Marine, and Nekkanti Sea Foods, play a pivotal role in advancing BT adoption. By implementing QR code-backed traceability, these companies can set industry benchmarks that encourage smaller stakeholders to follow suit. However, smaller processors and suppliers may face financial barriers in upgrading their traceability infrastructure (Kumar et al., 2020). Addressing these challenges requires industry-wide collaboration and potential public-private partnerships to reduce implementation costs. By pooling resources and expertise, stakeholders can create an inclusive ecosystem that promotes BT adoption across the entire supply chain, ensuring equitable access to transparency tools.

6.5.5 Diffusion of Blockchain Innovation in Indian Shrimp Supply Chains: A Critical Analysis

The adoption of BT in India’s shrimp sector aligns well with Rogers' Diffusion of Innovation (DOI) Model (2003), which categorizes adopters into innovators, early adopters, early majority, late majority, and laggards. Whereas, due to their capacity, large exporting firms could to act as early adopters, leveraging BT to meet stringent traceability demands from major importing markets such as the US and the EU. However, medium-sized farms may follow as the early majority, driven by competitive pressures and the visibility of successful BT adoptions. Nevertheless, the late majority and laggards, primarily small-scale shrimp farmers, face significant barriers that hinder adoption.

One major hurdle is the lack of digital infrastructure in Indian rural areas where most shrimp farms are located. Unlike advanced economies, many Indian farms lack reliable internet connectivity, data management systems, and BT-compatible software (Kamath, 2018). Addressing these infrastructural gaps would require targeted government initiatives aimed at rural digitization, such as subsidized internet access and training programs to build technological literacy.

Cost considerations are another critical challenge where small farmholders often operate with tight profit margins and may view BT as an added compliance burden rather than a value-added opportunity (Nakamura et al., 2022). Thus, collaborative models, such as ***cooperative BT networks*,** where costs are shared among multiple farms, could provide a more inclusive pathway for these smaller players. Industry-wide collaborations involving exporters, processors, and government agencies could further reduce the financial burden on small producers, ensuring reasonable access to BT.

Export market pressures also play a crucial role in driving diffusion of innovation. With importing countries increasingly emphasizing BT-based traceability, Indian exporters must adopt the technology to remain competitive in global markets. Regulatory bodies such as the Food Safety and Standards Authority of India (FSSAI) and the Marine Products Export Development Authority (MPEDA) could facilitate this transition by introducing BT-specific policies, financial assistance programs, and traceability standards to align with international requirements.

To accelerate the diffusion process, pilot programs showcasing successful BT adoption could serve as demonstrative proof, addressing the uncertainty of late adopters. In addition, tailored strategies to improve trials such as short-term pilots that allow farmers to experiment with BT at minimal risk could build trust in the technology's benefits. Over time, these measures could shift blockchain adoption from an emerging innovation to an industry-wide standard, ensuring India’s continued competitiveness in global shrimp markets.

6.5.6 Alternative Approaches for Study: The Case for Delphi Method and Broader Recruitment

This study might have preferred potential alternative approaches, such as the Delphi method which would have been a relevant technique for gathering insights on BT adoption in ISSC. The Delphi method is a structured, iterative process designed to collect expert opinions through a series of anonymous surveys or questionnaires, facilitating consensus on complex topics (Hsu & Sandford, 2007). Unlike traditional interviews, Delphi provides a means to engage a broader, more diverse panel of stakeholders, including policymakers, exporters, farmers, and technology providers, ensuring that multiple perspectives are integrated into the research findings.

Advantages of the Delphi Approach

The Delphi approach is well-suited to explore emerging technologies like BT as it well supports geographical dispersion and varied levels of expertise. For instance, involving international seafood buyers, regulatory authorities, and global technology experts could provide valuable insights into BT's global applicability and potential regulatory challenges. Moreover, the anonymity of the Delphi method minimizes bias by preventing dominant personalities from overshadowing other participants, thereby fostering a balanced consensus.

Challenges and applicability to this study

However, while the Delphi method offers significant advantages, its iterative nature could be time-intensive and resource-focused. For this study, which employed semi-structured interviews to explore stakeholder perspectives and a DCE study, a Delphi approach would have extended the research timeline substantially. Additionally, the thematic richness achieved through in-depth interviews might be diluted in the Delphi process due to its structured and repetitive design.

Broadening the Recruitment of Interviewees

Beyond the methodology, the recruitment process could also be expanded to include a more diverse range of participants. While the current sample integrated producers, processors, farmers, traders exporters, future studies could aim to include retailers, international seafood buyers, and consumers who directly engage with BT-enabled traceability labels. By including these groups, the research could gain a more comprehensive understanding of the entire ecosystem, from production to end-user interaction.

Practical Considerations for Broader Recruitment

Broader recruitment strategies could involve collaboration with industry associations like the MPEDA to reach stakeholders across different supply chain tiers. Partnering with NGOs or local cooperatives working with smallholder farmers could ensure the representation of marginalized voices. Leveraging digital platforms for recruitment, such as webinars or social media outreach, could also help engage younger and tech-savvy stakeholders, who are often underrepresented in traditional interviews.

Thus, while the semi-structured interview approach provided valuable insights, considering alternative methods like the Delphi technique or expanding participant recruitment could further enhance the study's robustness and inclusivity. Future research might benefit from employing mixed-method designs that combine the richness of qualitative interviews with the consensus-building strengths of Delphi, offering a more comprehensive lens to analyze BT adoption in ISSC.

6.5.7 Ethical Implications of BT Adoption in Shrimp Production: Transparency, Animal Welfare, and Industry Reputation

1. **Enhancing Transparency in Shrimp Farming Practices**

BT-enabled traceability systems ensure that every stage of shrimp production from hatchery to processing is digitally recorded and accessible to supply chain actors, including regulators and consumers (Jiang et al., 2023). This level of transparency allows stakeholders to verify compliance with ethical farming practices, including:

- Stocking density regulations to prevent overcrowding and stress among farmed shrimp.
- Water quality management to monitor oxygen levels, temperature, and contamination risks.
- Responsible antibiotic use to mitigate the overuse of chemicals and prevent antibiotic resistance (Rao et al., 2023).

By recording these parameters on an immutable BT ledger, farmers and processors are incentivized to adopt best practices, knowing that their actions will be publicly scrutinized by regulators, certification bodies, and even consumers. This shift toward greater accountability can prevent unethical shortcuts that might otherwise go undetected in conventional supply chains.

2. **BT and Animal Welfare: Moving Toward Ethical Shrimp Farming**

Animal welfare concerns in shrimp farming have gained international attention, particularly in export markets like the U.S. and the EU, where regulatory frameworks increasingly prioritize humane treatment and sustainability (Acciarini et al., 2023). While shrimp farming is not typically associated with animal welfare discussions to the same extent as livestock farming, key issues include:

- Deprivation of natural behaviours: High-density aquaculture restricts the ability of shrimp to exhibit normal behaviours, leading to stress and increased disease susceptibility.
- Pain perception and humane slaughter: Scientific research suggests that crustaceans may experience stress and suffering, raising concerns about ethical slaughter methods (Jespersen et al., 2020).
- Bycatch and environmental impact: While farmed shrimp reduce wild stock depletion, unsustainable practices such as mangrove deforestation for pond expansion can indirectly harm ecosystems.

BT can mitigate these ethical concerns by ensuring real-time monitoring of farming conditions, preventing malpractices such as extreme stocking densities and unsanitary conditions. If shrimp farms adhere to ethically responsible practices, these records can be linked to BT-enabled certifications, allowing consumers to make informed ethical purchasing decisions (Vázquez Meléndez et al., 2024).

3. Reputation and Market Positioning: The Ethical Advantage of BT

A major benefit of BT-enabled transparency is its impact on brand reputation and consumer trust. Ethical sourcing is increasingly becoming a competitive differentiator in global seafood markets. Companies that demonstrate commitment to responsible shrimp farming can leverage BT to:

- Gain consumer trust by providing tamper-proof proof of ethical farming practices.
- Enhance certification credibility by integrating blockchain records with sustainability certifications like ASC, BAP, and GlobalG.A.P..
- Secure premium pricing in markets where consumers value ethically sourced seafood, such as the European Union, the U.S., and Japan.

Moreover, retailers and food service chains are increasingly under pressure to source seafood responsibly. If BT-backed traceability systems verify ethical practices, retailers are more likely to favorably position Indian shrimp products, boosting market access and economic sustainability for Indian exporters.

4. Challenges and Ethical Limitations of BT in Shrimp Supply Chains

While BT offers significant transparency benefits, it does not automatically guarantee ethical shrimp production. The following limitations must be considered:

- Verification of Initial Data: If farm-level data (e.g., antibiotic use, stocking density) is manually entered, there remains a risk of misreporting or falsification before the data is recorded on the blockchain (Nandi et al., 2021).
- Exclusion of Small-Scale Farmers: High compliance costs for implementing BT traceability may exclude smallholder shrimp farmers, potentially creating an unfair advantage for large-scale aquaculture companies (Jiang et al., 2023).

- Consumer Interpretation of Data: While blockchain provides transparent records, not all consumers may understand or access this information effectively. A significant consumer education effort is required to translate BT data into meaningful insights for ethical purchasing decisions (Yang et al., 2024).

The adoption of BT in shrimp farming presents a significant opportunity to enhance ethical transparency, animal welfare considerations, and consumer trust. By ensuring tamper-proof documentation of farming practices, BT can strengthen supply chain accountability and help Indian shrimp exporters align with global ethical sourcing standards. However, implementation challenges remain, particularly in ensuring accurate data collection and equitable adoption among small-scale farmers. Moving forward, collaborations between policymakers, industry stakeholders, and technology providers will be critical in ensuring that BT adoption translates into meaningful ethical improvements in shrimp production.

6.5.8 Appearance of Products and Information in the Experiment: Enhancing Realism in Stated Choice Designs

The appearance of products and the way information is presented in stated preference experiments significantly influence how respondents engage with the choice tasks. In this study, the Discrete Choice Experiment (DCE) was designed to simulate real-world purchasing decisions by incorporating key product attributes relevant to shrimp consumers, such as BT-enabled traceability, food safety assurances, sustainability certifications, and pricing levels. However, as the examiners noted, there is potential to refine the experiment further to enhance realism, ensuring that consumer responses more accurately reflect actual purchase behaviour.

1. **Enhancing product representation through visual stimuli**

One of the limitations of text-based DCEs is that they rely solely on written descriptions of product attributes, which may not fully replicate the sensory and visual cues present in real-world shopping environments. Future studies could incorporate product images or packaging mock-ups to better reflect how consumers process information when making seafood purchase decisions (De Canio & Martinelli, 2021). For example:

- Visualizing BT Labels: Instead of only describing blockchain-traceable shrimp, the experiment could display mock product packaging with QR codes linked to blockchain verification systems. This would allow respondents to visualize how they would interact with traceability tools in an actual retail setting.
- *Incorporating Color and Design Elements:* Studies suggest that label design, color contrast, and certification logo placement significantly affect consumer perceptions of credibility and trustworthiness (Jiang et al., 2023). Including variations in label appearance could improve realism in the choice task.
- *High-Resolution Shrimp Product Images:* Using actual product images with packaging variations (e.g., fresh vs. frozen shrimp, organic vs. conventionally farmed) could better mimic real-life shopping scenarios in supermarkets or online marketplaces.

2. Improving Information Presentation for Realism

In many stated preference experiments, consumers are required to evaluate multiple attributes simultaneously, which can lead to cognitive overload and reduce response reliability (Hess & Daly, 2014). Future modifications to the study could address this by:

- *Presenting Information in a Layered Format*: Rather than overwhelming respondents with all product details in one screen, a progressive disclosure format could be used, where consumers first view basic product information and then opt to expand details (e.g., scanning a QR code for full traceability information).

- *Mimicking Supermarket Pricing Labels:* Instead of listing WTP values abstractly, product prices could be formatted as actual price tags, including price per pound, special discounts, and promotions. This approach aligns with research suggesting that price framing impacts consumer perception of value (Lusk & Schroeder, 2004).
- *Including Dynamic Choice Tasks*: Some experimental designs now incorporate eye-tracking studies or interactive online simulations, allowing researchers to observe how consumers naturally engage with product information rather than relying solely on stated preferences (Jiang et al., 2023).

3. Alternative Experimental Designs to Enhance External Validity

While DCEs provide valuable insights, real purchase behavior often differs from hypothetical choices due to factors such as budget constraints, shopping habits, and social influences (Lusk & Shogren, 2007). Future research could integrate:

- *Real Choice Experiments (RCEs):* These involve financially incentivized decisions, where participants make real purchases of blockchain-traced shrimp under controlled conditions. This reduces hypothetical bias and improves the realism of observed consumer preferences.
- *Supermarket Field Experiments*: Conducting in-store choice experiments, where consumers interact with blockchain-labeled shrimp in actual retail environments, would provide stronger ecological validity.

- *Virtual Reality (VR) Shopping Simulations*: Emerging research suggests that VR grocery stores can replicate real-world shopping behaviors more effectively than static online surveys (De Canio & Martinelli, 2021). Implementing immersive experimental settings could enhance the authenticity of consumer responses.

Strengthening the realism of experimental designs

While the current study provides meaningful insights into consumer WTP for blockchain-traced shrimp, further refinements in product visualization, information presentation, and experimental design could improve the realism and external validity of the findings. Incorporating visual product representations, interactive choice tasks, and real-world purchasing contexts would bridge the gap between stated and actual consumer behaviour, strengthening the applicability of results to real-market conditions.

6.6 Conclusion

This thesis was divided twofold to investigate two different parts of ISCC which is both the supply and demand section and thus contributed to address the current knowledge gap on ISSC stakeholder perception on BT adoption in ISCC followed by investigating consumer preferences and WTP for BT certified shrimp. To the best of the author's knowledge, both of these studies are the first empirical studies on BT adoption in ISSC from these two perspectives i.e. firstly, to examine the perceptions and beliefs of ISSC stakeholders on the benefits and costs of adopting BT in the sector; and second to investigate consumers' valuation of BT-certified shrimp. Which, therefore, would serve as a benchmark for further investigation and exploration on this topic.

Overall, the results show that ISSC stakeholders noted a positive enthusiasm for BT adoption in the sector which they believe would provide a good solution to their current business challenges. The lack of efficient traceability in the ISSC has made it difficult to identify the origin of the use of antibiotics which is one of the major concerns in the international shrimp market and affecting each stakeholder economically. Thus, addressing the rising demand of shrimp consumers to make informed decisions while buying shrimp, has been acknowledged well by the majority of ISSC. Respondents have shown interest in opting for a single platform on BT for better coordination through a transparent, and trustworthy system, that offers end-to-end visibility and trust-building in the overall supply chain. These findings are not corroborated by any other studies which shows the novel findings of this study on the topic.

Furthermore, we found that consumers are willing to pay a premium price for BT-certified shrimps. In particular, we found that when food safety benefits of the adoption of BT-certified shrimp are provided, compared to food frauds and sustainability benefits consumers are willing to pay a higher price. In terms of consumer heterogeneity, it was seen that young consumers from high-income groups and having children under 18 in households are too willing to pay premium prices for BT traceable shrimps. Lastly, consumers have shown a positive sign of acceptance and readiness for BT traceable shrimp.

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Appendices

Appendix A-List of the literature reviewed on BT implementation in Agri-food sector including fisheries and aquaculture.

Author	Aim of the study	Country of Investigation	Method	Product of research	Findings
Akella *et al.*, (2023)	A systematic review of BT adoption barriers and enablers for smart and sustainable agriculture	Australia	Literature review	General agriculture	-Barriers of BT implementation- (i) lack of government regulations, (ii) resource capital requirements, (iii) security and privacy concerns, (iv) lack of standards, (v) trust, (vi) scalability issues, (vii) awareness and (viii) ease of use. - Enablers: (i) stakeholder collaboration, (ii) enhancing shared responsibilities of partners, (iii) increasing customer trust, quality of service, sustainable value chains and infrastructure, (iv) data security and useability, (v) improving efficiency in supply chains and (vi) enhancing agricultural democratization
Bandinelli *et al.*, (2023)	To study BT and consumer behaviour in the ancient wheat sector.	Italy	Technology Acceptance Model	Ancient Wheat pasta	-Immutability of BT enabled data throughout the AFSC, assures the end consumer with a high-quality product. -Cost one of the key factors hindering BT adoption
Karnaushenko et al., (2023)	To study application of BT in the economic activity of agricultural enterprises	Ukraine	Literature review	General agriculture	-BT provides effective management and monitoring of data on the general state of agricultural production, helps reduce risks and costs. -BT ensures security and transparency for all stakeholders with enhanced brad reputation.
Peng *et al.*, (2023)	To review on BT smart contracts in the agri-food industry on current state, application challenges and future trends	China	Literature review	General agriculture	-Benefits-Increased security, data authenticity, automation on data collection and analysis, cost reduction, reduce operational risk, improved traceability and supervision efficiency. -Disadvantages- Less practical implementation, legal issues, low efficiency, energy consumption

Thompson and Rust, (2023)	To examine the social, cultural, and institutional factors causing innovation resistance to digital technology in seafood supply chains.	Australia	Framework	Fish	-BT has FASC stakeholders such as wholesalers who were resistant on BT adoption due to unclear on sales volumes and preferred species. -Many fishers, aquaculturists, and restaurateurs were keen to adopt BT.
Meera et al., (2023)	To study barriers of BT adoption in seafood exports	India	TOPSIS method	Seafood general	-Barriers of BT adoption- regulatory uncertainty, lack of regulatory compliance, and higher implementation costs which need to be reduced for better adoption of the BT. -Noted on consumers to absorb high costs as part of value addition in the value chain.
Mileti et al., (2023)	To study BT Traceability in Trading Biomasses Obtained with an Integrated Multi-Trophic Aquaculture	Italy	Case study	Fish	- The implementation of BT is costly and could be prohibitively expensive for small family fish farmers. - Presence of gap between the possibility of applying BT versus the aquaculture sector's ability to embrace them at all levels of the supply chain. - Government and national institutions should legislate and provide research funds for multi- disciplinary projects.
Liu and Yu, (2023)	To study efficiency analysis of BT agriculture products E-commerce cold chain traceability system based on Petri net	China	Petri Net Modelling	General Agriculture	- Ensured food safety for whole supply chain -Common governance to standardize the market economic order - Reduced enterprise costs and improved enterprise benefits -Increased farmers' income and targeted poverty alleviation
Luna et al., (2023)	To study the challenges of EU's environmental policy compliance in aquaculture	Spain	Framework	Fish	-Proposed a novel blockchain framework, along with the strategic implementation of smart contracts. -Framework allows fishers/aquaculturist to improve compliance with the requirements while maintaining efficiency, profitability and global competitiveness.
Rampone et al., (2023)	To demystify misconceptions on BT and present real opportunities in agri-food sector	Italy	Framework	General agriculture	- BT helps to organise and re-engineer the relationships among stakeholders enduring more trust in the system.

					-BT enhances consumer trust in the system and all stakeholders due to a single source of true data distributed with all.
Zhai et al., (2023)	To investigate the role of information heterogeneity in BT-based fresh fruits traceability systems	China	Best-worst scale experiment, Mixed Logit Model	Fresh fruits	-Consumers ranked the following attributes most valuable: testing information, production inputs (e.g. pesticides), quality certification and grades information attributes, and supplier and logistics information were the least valuable attributes. -Consumer segments identified from latent class analysis- (a) sensitivity for authoritative information, (b) preferences for comprehensive information, (c) information preferences equally, and (d) preferences for production inputs information
Bager, et al., (2022)	To assess BT potential in coffee supply chains and to identify barriers and opportunities to promote sustainability.	Belgium	Case study	Coffee	-BT is no silver bullet to deliver AFSC sustainability, whereas knowledge on provenance and transparency of information on quality and sustainability can help trigger transformation of consumer behavior. -The actual value lies in digitizing the supply chain to increase efficiency and reduce costs, disputes, and fraud, with more end-to-end product provenance.
Tolentino-Zondervan , et al., (2022)	To identify future prospects of BT applications in global fishery and aquaculture value chains	Netherlands	Literature review	Fish	-Application of BT is mostly in vertical fish value chain and limited in the horizontal dimension of the value chain in terms of traceability and payment/incentive. -Access to financing (decentralised financing) can motivate developing country producers to adopt BT in developing countries
Köhler, et al., (2022)	To explore BT based technologies (BTT) and voluntary sustainability standards (VSS) interact within agro-food supply	Denmark	Case study analysis	Multiple	-There can be synergetic overlaps among VSS and BBT cases, particularly regarding transparency and labelling. - Blockchain technology may further be used as a tool to overcome bottlenecks of insufficient data and inconsistent record-keeping of existing VSS.

	chain sustainability governance.				
Olsen *et al.*, (2022)	To study applications, benefits and costs of BT in seafood supply chains	Norway	Case study	Fish	BT is a good solution to improve the supply chain stakeholder relations, better management of the production, less food waste and good contact with end-customers with transparency in data sharing.
Khan et al., (2022)	To design a BT-enabled transparent and traceable framework to enhance the export potentiality of Bangladeshi shrimp	Bangladesh	Framework design	Shrimp	Shrimp farmers engagement in the safety and quality assurance and in the certification, process will encourage them to have better control over the market and incentive to produce high-quality shrimp for high value market.
Bhat *et al.*, (2022)	To share an architecture framework for AFSC based on IoT and BT to address current challenges in the AFSC.	Taiwan	Framework design	General	-The Agri-SCM-BIoT architecture is effective to address storage, scalability, interoperability, security and privacy issues, and storage concerns with existing AFSCs.
Rowan, (2022)	To study how digital transformation can help support and meet expansion needs of the fisheries/aquaculture industries.	Ireland	Literature review	Fish	-Digital technologies can help address these concerns and also potentially disrupt FASC. -BT can transform fishery by improving safety of business models through combatting fraud, food traceability from farm to fork, food waste and food-related diseases.
Song *et al.*, (2022)	To study BT adoption in AFSC for better sustainability	China	Game theory	General	-The total cost of technology adoption has a significant impact on the government and agricultural enterprises. -The government plays an important guiding role in adoption of BT.
Patel et al., (2022)	To design a framework for BT adoption in food supply chain	India	Framework design	General	-BT shows strong potential to resolve issues like data integrity, with enhancing transparency, security, and reduction in food frauds. -Potentially a large investment would be required for BT adoption in AFSC

Patro *et al.*, (2022)	To study BT-Based traceability for the FASC	UAE	Framework design	Fish	- BT enabled solution can be adopted as a measure to improve the current practices in the fish industry -Proposed a private Ethereum BT-based solution to handle the FASC operations in a decentralized, traceable, accountable, transparent, private, secure, and trustworthy manner.
Vu et al., (2022)	To develop a implementation model for BT in AFSC	UK	Semi-structured qualitative interviews	General	-Model design included 3 stages BT adoption- Initiation, adoption, implementation. -Determinants for adoption- Technology, organisation, environment, and management.
Kassanuk and Phasinam, (2022)	To design BT based smart agriculture framework to ensure safety and security	Thailand	Framework	General	-BT-based agriculture infrastructure is suggested that records data on farmers and farming in a safe and securely. -BT shares a key solution on critical issues of middlemen in FASC due to visibility and transparency.
Awan *et al.*, (2021)	Combo smart model with a novel scheme for the transformation of traditional agriculture to smart agriculture	Pakistan	Framework	General	BT with the IoT can be more advantageous to track food lifecycle, which avoid significant food wastage, and detect and eliminate the cause of foodborne disease in couple of seconds as compared to current system.
Treiblmaier *et al.*, (2021)	To explore Intra- and Interorganizational Barriers to BT adoption in agri-food sector	USA	Mixed methodology	General	Barriers identified**-** *Intra-organizational:* Financial constraints, Lack of management commitment and support, Lack of new organizational policies for using technology, Lack of knowledge and expertise, Difficulty in changing organizational culture, Hesitation to convert to new systems, Lack of tools for BT implementation whereas, *Interorganizational*: Problems in collaboration, communication, and coordination in the supply chain. Information disclosure policy.

					Problems with integrating blockchain technology, cultural differences.
Shew *et al.*, (2021)	To study consumer valuation for BT traceable beef	USA	Quantitative study	Beef	-US consumers preferred USDA certified beef and were willing to pay premium against BT certified beef. -BT would incur high costs such as implementation, transactional and other infrastructure development costs which need to be considered by businesses adopting BT, which benefits in long term.
Tsolakis *et al.*, (2021)	To design supply network to address United Nations Sustainable Development Goals in Thai fish industry	Thailand	Case study	Fish	There is a data asymmetry in supply chains to achieve Sustainable Development Goals.
Vu et al., (2021)	To study barriers and enablers of BT adoption in food supply chains	UK	Literature review	General	-Enablers-Increasing transparency and efficiency were two key internal drivers for BT; pressure from consumers, competitors and regulatory bodies were critical external driver -Barriers-privacy against transparency dilemma, high implementation cost, the supply chain's readiness for BT, and the scalability.
Hu et al., (2021)	To find a framework solution to trust crisis using BT in organic AFSC	China	Framework	Organic agri supply chain	-The features of BT such as tamper-resistant, trust-free, transparent, decentralized, and immutable are favorable for adoption in organic supply chain.
Blaha & Katafono, (2020)	To study BT application in fisheries value chain	Italy	Literature review	Fisheries	-BT application must be in compliance at different levels of value chains custody (e.g., flag state, coastal state, port state, processing state, and end market state). -Barriers in BT adoption among which regulatory uncertainty, lack of trust among users, lack of coordination in the network must be considered. -The costs involved in BT adoption (development or subscription) and technical infrastructure requirement must be considered on adoption.

Demestichas et al., (2020)	To conduct a thorough research in the literature concerning traceability techniques and BT and their combination in the agriculture sector	Greece	Literature review	General	-To implement this new system to be successful, it should promise the following: (i) reduce costs, (ii) reduce risk, (iii) save time, and (iv) increase trust and transparency -BT can advantageously help to achieve traceability by irreversibly and immutably storing data, and it generates a unique level of credibility that contributes to a more sustainable food industry. -Stakeholders would adopt this only when they are convinced that the proposed method is user-friendly, increases productivity and brings added value.
Kayikci *et al.*, (2020)	To study BT suitability to address the prevention of food loss throughout the supply chain	Turkey, India	Semi-structured interviews	Multiple food companies	-BT will ensure the non-manipulation of data, transparency, security, and collaboration among the stakeholders. -IoT devices need to be implemented throughout the food supply chain in order to capture comprehensive and consistent data across multiple parties and transmit the data to the blockchain. -All the parties in a blockchain have a responsibility to distribute the right information.
Patelli & Mandrioli, (2020)	To study BT enabled traceability in agrifood sector	Italy	Literature review	General	-Along with efficient traceability offered by BT, several challenges such as inadequate knowledge among stakeholders such as farmers, and costs needs to be addressed. -BT is noted as secure, reliable and transparent tool to ensure food safety and integrity.
Howson, (2020)	To improve marine conservation and fisheries supply chain management using BT	UK	Literature review	Fish	-BT enable larger companies to cost effectively protect their brand images due to transparency and visibility in the sector. -Unless data input is automated, BT fixes marine management will be subject to 'garbage in, garbage out'.

Cruz and da Cruz, (2020)	To implement a BT traceable platform in the UK	Portugal	Framework	Fish	-BT is suitable for traceability, building a trustless stakeholders' system where each stakeholder will have a same copy of data.
Xu, et al., (2020)	To investigate the impact of blockchain technology on the cost of food traceability supply chain	China	Literature review	N/A	-The operations cost of traditional food traceability supply chain system is high -Introduction of BT will reduce the transaction cost, quality cost, time cost, activity cost, and supply chain traceability additional cost in the food supply chain cost.
Rejeb *et al.*, (2020)	To conduct a review of Potentials, Challenges and Future Research Directions of BT application in food industry	Hungary	Bibliometric analysis	General	-The main benefits of BT in AFSC were improved food traceability, enhanced collaboration, operational efficiencies and streamlined food trading processes. -Potential challenges include technical, organizational and regulatory issues.
Duan et al., (2020)	To analysis content-based literature review in BT adoption within food supply chain.	China	Literature review	General	-Combining with current Internet of Things (IoT) BT can further improve the efficiency of supply chain management and traceability system. -BT shows a significant potential to address food crisis and bring a more trusted future on food security and quality. -Combining all the features, BT can eliminate the risks of transactions in a lack of trust environment, increase supply chain visibility and transparency, improve efficiency, and protect every stakeholder's benefit
Behnke and Janssen, (2020)	To identify boundary conditions for sharing assurance information to improve traceability	Netherlands	Exploratory research/ semi-structured interview	Dairy Food	The findings show that BT can be used in supply chains for traceability of goods and can be used to create transparency in the goods supply.

Bumblauskas *et al.*, (2020)	To track products from farm to fork using BT and internet of things (IoT) enabled technologies.	USA	Use-Case Design	Eggs	Traceable and transparent food supply chains with BT, for companies would build better relationships with their customers of with a rise in efficiency, diminishing the risk and cost of food recalls, fraud, and product loss.
Kamble, et al., (2020)	To understand the level of analytics used in sustainable AFSC processes from where the data is collected and explore BT implementation.	India	Literature review	General	-The present literature highlights the increasing demand from the consumers for complete information on the product, reflecting the need for more transparent and lack of trust in the current AFSC using BT. -Internet of things, BT, and big data technologies are potential enablers of sustainable agriculture supply chains
Köhler and Pizzol, (2020)	To provide new critical insights on how BT can be implemented in the food supply chain and to further the discussion of social and environmental implications of BT-based technologies	Denmark	Case study, Qualitative research	General	-The setup of the BT influences both the system's transparency, customizability, and speed. -Data asynchrony issues can be overcome using BT
Motta et al., (2020)	To investigate the application potential of BT in the agri-food industry	Netherlands	Case study approach	General	-Although in its infancy, governance issues are important in BT, as broader partnerships are required for successful, sustainable applications. -BT addressed efficiently issues of trust and transparency, with facilitating information sharing among AFSC stakeholders
Rogerson and Parry, (2020)	To investigate BT status beyond cryptocurrencies to enhance visibility and trust in supply chains, their limitations and potential impact	UK	Qualitative analysis, Case studies using semi structured interviews	Agriculture, Fishing, Wine and infant food formula	-BT provides visibility of exchanges and reliable data in fully digitised supply chains and provides provenance and guards against counterfeit goods due to transparency.

					-Challenges in BT adoption- trust of the technology, human error and fraud at the boundaries, governance, consumer data access and willingness to pay.
Feng *et al.*, (2020)	To review the BT characteristics and identify BT-based solutions to address food traceability concerns, and propose an architecture design framework and suitability application analysis flowchart of BT based food traceability systems	China	Framework/ architecture	General	Although BT has been acknowledged as a promising solution to address food traceability issues, there is a very limited understanding on its specific characteristics and functionalities for food traceability management. The results of the study contribute to better understanding and knowledge on how to improve the food traceability by developing and implementing BT-based traceability systems.
Prashar et al., (2020)	To enable the real-time monitoring to bring transparency in the food supply chain using BT.	India	Framework/ architecture	General	The proposed traceability system introduces a private BT shows a throughput of 161 transactions per second with a convergence time of 4.82 s and was found effective in the traceability of the agricultural products.
Qian et al., (2020)	To review the food traceability system from governmental, corporate, and consumer perspectives in the European Union and China	China	Mixed methodology	General	-The functionality of BT would be an ideal platform to develop such a system, with the aim of mitigating risks and increasing trade channels. - Consumer value and perception must be considered while adopting BT system, varies with country location.
Xiong *et al.*, (2020)	To examines the applications of BT in food supply chains, agricultural insurance, smart farming	China	Literature review	General	It provides a secure way of storing and managing data, which facilitates the development and use of data-driven innovations for smart farming and smart index-based agriculture insurance.
Yadav et al., (2020)	To identify major barriers in BT adoption in Indian AFSC.	India	Delphi, ISM-DEMATEL,		Main barriers of BT adoption in Indian AFSC-Lack of government regulation and lack of trust among stakeholder to use BT.

			Fuzzy-MICMAC		
Mirabelli and Solina, (2020)	To review the literature about the applications of the BT in the agricultural supply chains, focusing on food traceability issues.	Italy	Literature review	General	The BT use in agricultural sector is in its early stage, thus there is an almost total absence of real case studies, thus not currently clear how an agricultural supply chain can obtain benefits from an economic and organizational point of view through the implementation of a real BT-based platform.
Scuderi, et al., (2019)	To reduce the information asymmetry, between producers and consumers, of Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) through BT.	Italy	Case study approach	Blood Oranges	BT shows a promising hold for companies, and is a unique tool to control the system of information related to the product promising traceability and transparency
Ray *et al.*, (2019)	To identify the factors that influencing BT adoption in the food supply chain.	India	Mixed methodology	General	-BT can create an impact on the food supply chain -Stakeholders are favorable to consider while adopting BT in the various clusters of food supply chain in the Indian context
Liao and Xu, (2019)	To propose a study on BT combined with agricultural product trading platforms	China	Framework/ architecture	Tea	-The asymmetric use of BT encryption and hashing algorithms allow data to have non-transferable features through which traceability of tea can be achieved. -BT features such as decentralization, consensus, trust, and reliable database can effectively reduce the cost of agricultural product traceability system and ensure the safety and reliability of agricultural product traceability information.
Pearson *et al.*, (2019)	To examine the traceability, key challenges and barriers using BT to securely link the	UK	Literature review	General	Data standardization is essential in the food domain, ease of use to remove barriers to entry to the food supply chain, governance mechanisms, enhancement of the technology to cope with a large amount of data

	entire food supply chain, from producer to end user.				(scalability), privacy mechanisms to protect users and an iterative approach is required to underpin the adoption of the technology across the whole chain.
Antonucci et al., (2019)	To show a panorama of the scientific studies (enriched by a terms mapping analysis) on the use of BT in the agri-food sector, from both an entirely computational and an applicative point of view.	Italy	Literature review	General	Having the role to store and distribute an updated copy of each block in a food supply-chain, result of crucial importance.
Surasak et al., (2019)	To designed and develop Thai agriculture products traceability system using BT and Internet of Things. BT,	Thailand	Framework design	General	The BT integration with IoT is found very beneficial for the developed traceability system. The novel system could have a huge impact on food traceability and supply chain management become more reliable as well as rebuild public awareness in Thailand on food safety and quality control.
Kamble et al.,(2019)	To identify and establish the relationships between the enablers of BT adoption in AFSC.	India	Combined Interpretive Structural Modelling (ISM) and Decision-Making Trial and Evaluation Laboratory (DEMATEL)	General	Traceability was the most significant reason for BT implementation in ASC followed by auditability, immutability, and provenance.

Salah *et al.*, (2019)	To study an approach that leverages for soybean tracking and traceability	UAE	System design and architecture	Soybean	-Ethereum BT and smart contracts efficiently perform business transactions for soybean tracking and traceability across the AFSC. -Study proposed solution eliminates the need for a trusted centralized authority, intermediaries and provides transactions records, enhancing efficiency and safety with high integrity, reliability, and security -BT has key challenges related to scalability, governance, identity registration, privacy, standards, and regulations.
Montecchi, et al., (2019)	To develop a provenance knowledge framework and show how its application can enhance assurances and reduce perceived risks via the application of BT	UK	Provenance knowledge framework	General	-BT promises to create transparent supply chains that generate provenance knowledge that allow all players to trace the origin, certify authenticity, track custody, and verify integrity of products. -This reduces customers' perceived risks and strengthen customers' confidence in the purchase and consumption of products.
Creydt and Fischer, (2019)	To study BT combined with Internet of Things (IoT) in the context of food traceability	Germany	Literature review	General	To ensure the traceability of food trade networks BT algorithms incorporate a high potential, as data can be stored in an unmodifiable way and enabling quick tracking across all process steps.
Borrero, (2019)	To provide an overview of BT (Hyper ledger Fabric) and its application in agriculture	Spain	Framework design	Fruits and Vegetables	Current system is inefficient and unreliable. This new supply chain architecture via BT can maintain confidentiality and can spread data effectively among the participants that use it.
Basnayake and Rajapakse, (2019)	To implement a BT based solution to verify the food quality and the origin of the agricultural supply chain.	Srilanka	Framework design	Organic food	Trust and transparency were successfully ensured by the proposed mechanism.

Zhao *et al.*, (2019)	To study implications and challenges for BT in AFSC management	China	Systematic literature network analysis	General	Six challenges have been identified including storage capacity and scalability, privacy leakage, high cost and regulation problem, throughput and latency issue, and lack of skills.
Kamilaris et al., (2019)	To examine the impact of BT in AFSC, presents existing ongoing projects and initiatives, and discusses overall implications, challenges, and potential	Spain	Literature review	General	Findings indicate that BT is a promising technology towards a transparent supply chain of food, with many ongoing initiatives in various food products and food-related issues
Baralla *et al.*, (2019)	To proposes a BT based generic agri-food supply chain traceability system to implement the "from-farm-to-fork" (F2F) model.	Italy	Case study approach	Wine, other food	All the involved operators can identify any participants along the entire supply chain, increasing the degree of trust between organizations and individuals, with autonomous management of temporal sequence of activities.
Mondal *et al.*, (2019)	To propose a BT inspired Internet-of-Things architecture for creating a transparent food supply chain.	India	Information architecture	General	Any consumer or retailer can check the public ledger to obtain information regarding the specific food packages. The information helps in updating the shelf life, identifying key bottlenecks in the Food Supply Chain, implementing targeted recalls, and moreover increasing visibility.
Aich *et al.*, (2019)	To study differences in traditional supply chains and IoT-BT enabled supply chains across sectors	India	Case study	Several including food and fishery supply chain	-IoT integrated blockchain based supply chain system able to remove the problem and make the system more efficient and trustworthy. -Seafood supply chain has several benefits of integrating IoT-BT into the network such as reduced frauds (mislabelling),better food safety, consumers trust due to more transparency in the system compared to traditional one.

Yuxin and Xu, (2019)	To study traceability Based on BT in Tea Quality Safety Management Traceability System.	China	Framework design	Tea	BT features such as decentralization, transparency, consensus, trust and security would efficiently ensure the safety and reliability of tea -BT would cut the product traceability cost of agricultural system
Tsang *et al.*, (2019)	To propose a BT–IoT-based food traceability system to deploy a total traceability shelf-life management system for managing perishable food.	Hong Kong	Case study approach	General	BT would be helpful to prevent quality discrepancy and serious deterioration pro-active strategies that can be established to build better management of perishable food e-commerce.
Tripoli and Schmidhuber, (2018)	To facilitate a better understanding of the opportunities, benefits, and applications of BT in the agriculture sector.	Italy	Literature review	General	The technological platform introduces a new digital institution of trust to lower uncertainty between buyers and sellers and brings greater efficiency, transparency, and traceability to the exchange of value and information, which is fundamental to the agricultural sector and the entire global economy.
Sander, et al., 2018)	To investigate meat traceability to evaluate potential of acceptance of BT.	USA	Qualitative study-semi-structured interviews	Meat	The adoption of BT, in combination with DNA coding, seems promising as a solution to many of the issues that currently plague transparency and traceability system.
Hua *et al.*, (2018)	To investigate BT based provenance for agricultural products with duplicated and shared bookkeeping	China	P-2-P network framework	General	Applying BT techniques to the provenance of agricultural product supports building a reliable community among different stakeholders around agriculture production

Lucena et al., (2018)	To assess grain quality assurance tracking based on a BT business network.	Brazil	Case study	Soybean	Results support a potential demand for a BT based certification that would lead to an added valuation of around 15% for genetically modified-free soy in the scope of a Grain Exporter Business Network in Brazil.
Lin et al., (2018)	To propose a trusted, self-organized, open, and ecological food traceability system based on BT and Internet of Things (IoT) technologies	China	Framework design	General	BT and IoT technologies can help us to build a trusted, self-organized, open, and ecological smart agriculture system, which involves all parties in the ecosystem.
Mao *et al.*, (2018)	To provide a BT-based credit evaluation system to strengthen the effectiveness of supervision and management in the food supply chain.	China	Use of Long Short-Term Memory (LSTM)	General	-Due to BT, traders can be held accountable for their actions in the process of transaction and credit evaluation. -Other regulators can gather more reliable, authentic, and sufficient information about traders.
Caro *et al.*, (2018)	To present AgriBlockIoT, and compare the performance of Etherium and Hyperledger sawtooth, in terms of latency, CPU, and network usage, to highlight their main pros and cons.	Italy	Framework design	General	AgriBlockIoT enables the integration of IoT and BT technologies, creating transparent, fault-tolerance, immutable and auditable records which can be used for an Agri-Food traceability system
Tse *et al.*, (2018)	To study application of BT in information security of the food supply chain and compare it with the traditional supply chain system	China	Empirical research methods, PEST analysis	General	Promoting the BT is a well worth technology for helping government track, monitor and audit the food supply chain and helping manufacturers to record the transactions in authenticity
Casado-Vara *et al.*, (2018)	To propose a simulation model for BT enables agri-food supply chain.	Spain	Framework design	Agriculture general	BT enabled food supply chain model also helps circular economy model with use of efficient traceability in the supply chain.

(Galvez, et al., 2018)	To examine the potential of BT for assuring traceability and authenticity in the food supply chain.	Spain	Case study approach	Agriculture general	BT are powerful tools to avoid food fraud and are better to achieve traceability and allows all stakeholders to check the entire history and current location, for example, of a product along with transparency for all participants.
Ge *et al.*, (2017)	To study impact specific aspects to apply BT in AFSC, and conceptualise and develop a proof of concept in an application based on a use case concerning table grapes from South Africa	Netherlands	Literature review / Pilot study	Grapes	-BT is not a panacea to all problems and faces data storability issues. The mechanics and social-economic implications of BT are still vague for most stakeholders. -Most stakeholders are not ready yet for a paradigm shift towards BT-ready food chain.
Kumar and Iyengar, (2017)	Application scenario in the rice industry in India using BT	India	Theoretical study	Rice	Data immutability and redundancy is expected to lower the system error and facilitate traceability of rice provenance, which would build trust among the actors of the supply chain.
Tian, (2017)	To develop a supply chain traceability system for food safety based on Hazard Analysis Critical point (HACCP), BT & Internet of things (IoT)	China	Framework design	Rice	This system will deliver real-time information to all supply chain members on the safety status of food products, extremely reduce the risk of centralized information systems, and bring more secure, distributed, transparent, and collaborative.
Tian, (2016)	To utilise and develop situation of RFID (Radio-Frequency Identification) and BT and analyze the advantages of using in the AFSC traceability system	China	Framework design	General	Traceability with trusted information in the entire agri-food supply chain, would effectively guarantee the food safety, by gathering, transferring, and sharing the authentic data of AFSC in production, processing, warehousing, distribution etc.

Appendix B- List of the authors, journals, and type of journals

Author	Name of the journal	Type of the journal
Akella *et al.*, (2023)	Big Data and Cognitive Computing	Computer Science
Bandinelli *et al.*, (2023)	Cleaner Logistics and Supply Chain	Logistics and Supply Chain
Karnaushenko et al., (2023)	Agricultural and Resource Economics: International Scientific E-Journal	Economics
Peng *et al.*, (2023)	Computers and Electronics in Agriculture	Computers and Electronics in Agriculture
Thompson and Rust, (2023)	Technology in Society	Technology
Meera et al., (2023)	Sustainable Operations and Computers	Economics, environment and social perspectives
Mileti et al., (2023)	Sustainability (Switzerland)	Environment
Liu and Yu, (2023)	Heliyon	Physical, social & medical sciences
Luna et al., (2023)	Marine Policy	Ocean and marine policy studies
Rampone et al., (2023)	Economia Agro-Alimentare/ Food Economy	Agriculture and Food Economy
Zhai et al., (2023)	International Food and Agribusiness Management Review	Agriculture and Food Business
Bager, et al., (2022)	Current Research in Environmental Sustainability	Environment
Tolentino-Zondervan, et al., (2022)	Aquaculture	Aquaculture
Köhler, et al., (2022)	Technological Forecasting & Social Change	Sustainability
Olsen *et al.*, (2022)	Nofima (Norweigian Institute of Food, Fisheries and Aquaculture Research)	Fisheries
Khan et al., (2022)	Smart Agricultural Technology	Agriculture

Bhat *et al.*, (2022)	MDPI-Agriculture	Agriculture
Rowan, (2022)	Aquaculture and fisheries	Aquaculture
Song *et al.*, (2022)	Sustainability	Sustainability
Patel et al., (2022)	Procedia Computer Science	Computer science
Patro *et al.*, (2022)	IEEE Access	Electrical and Electronics
Vu et al., (2022)	International Journal of Logistics Research and Applications	Supply chain Management
Kassanuk and Phasinam, (2022)	Materials Today: Proceedings	Material sciences
Awan *et al.*, (2021)	Wireless Personal Communications	Science+Business media
Treiblmaier *et al.*, (2021)	MDPI-Logistics	Logistics and operations
Shew *et al.*, (2021)	Applied Economic Perspective and Policy	Applied Economics
Tsolakis *et al.*, (2021)	Journal of Business Research	Business and management
Vu et al., (2021)	Production Planning & Control	Logistics and operations
Hu et al., (2021)	Computers & Industrial Engineering	Computer science
Blaha & Katafono, (2020)	Fisheries and aquaculture	Fisheries and aquaculture
Demestichas et al., (2020)	Applied Sciences	Science
Kayikci et al., (2020)	Production Planning & Control	Logistics and operations
Patelli & Mandrioli, (2020)	Journal of Food Science	Food science
Howson, (2020)	Marine Policy	Marine conservation

Cruz and da Cruz, (2020)	ICSOFT 2020 - Proceedings of the 15th International Conference on Software Technologies	Information technologies
Xu, et al., (2020)	OP Earth and Environmental Science	Earth and Environmental Science
Rejeb et al., (2020)	MDPI-Logistics	Logistics and operations
Duan et al., (2020)	International Journal of Environmental Research and Public Health	Environmental and Public Health
Behnke and Janssen, (2020)	International Journal of Information Management	Information management
Bumblauskas et al., (2020)	International Journal of Information Management	Information management
Kamble, et al., (2020)	International Journal of Information Management	Information management
Köhler and Pizzol, (2020)	Journal of Cleaner Production	Environmental sciences
Motta et al., (2020)	Frontiers in Blockchain	Blockchain
Rogerson and Parry, (2020)	Supply Chain Management	Supply Chain Management
Feng et al., (2020)	Journal of Cleaner Production	Environmental sciences
Prashar et al., (2020)	Sustainability (Switzerland)	Environmental, cultural, economic, and social sustainability of human beings
Qian et al., (2020)	Trends in Food Science and Technology	Food Science
Xiong et al., (2020)	Frontiers in Blockchain	Blockchain
Yadav et al., (2020)	Resources, Conservation & Recycling	Resources, Conservation & Recycling
Mirabelli and Solina, (2020)	Procedia Manufacturing	Manufacturing engineering
Scuderi, et al., (2019)	Quality-Access to Success	Multi-disciplinary
Ray et al., (2019)	International Journal of Management Studies	Management studies

Liao and Xu, (2019)	Journal of Physics	Physics
Pearson et al., (2019)	Global Food Security	Agriculture, Policy, Economics, and Environment
Antonucci et al., (2019)	Journal of the Science of Food and Agriculture	Agriculture
Surasak et al., (2019)	IJACSA) International Journal of Advanced Computer Science and Applications	Computer Science
Kamble et al.,(2019)	International Journal of Information Management	Information management
Salah et al., (2019)	IEEE Access	Electrical and Electronics
Montecchi, et al., (2019)	Business Horizons	Business
Creydt and Fischer, (2019)	Food Control	Food science
Borrero, (2019)	CIRIEC-Espana Revista de Economia Publica, Socialy Cooperativa	Economics
Basnayake and Rajapakse, (2019)	IEEE Access	Computer Sciences
Zhao et al., (2019)	Computers in Industry	Computer Sciences
Kamilaris et al., (2019)	Trends in Food Science and Technology	Food science
Baralla et al., (2019)	Lecture Notes in Computer Science	Computer Sciences
Mondal et al., (2019)	IEEE Internet of Things Journal	Electrical and Electronics
Aich et al., (2019)	IEEE (21st Conference in advance communications technology)	Communications technology
Yuxin and Xu, (2019)	Journal of Physics: Conf. Series	Physics
Tsang et al., (2019)	IEEE Access	Computer Science
Tripoli and Schmidhuber, (2018)	FAO and ICTSD: Rome and Geneva	Food and Agriculture

Sander, et al., 2018)	British Food Journal	Food Science & Technology
Hua et al., (2018)	IEEE Intelligent Vehicles Symposium, Proceedings	Multi-disciplinary
Lucena et al., (2018)	Symposium on Foundations and Applications of BT	Blockchain
Lin et al., (2018)	International journal on Computer Science & Engineering	Science and Engineering
Mao et al., (2018)	International Journal of Environmental Research and Public Health	Environmental and Public Health
Caro et al., (2018)	IoT Vertical and Topical Summit on Agriculture - Tuscany	Agriculture
Tse et al., (2018)	IEEE Access	Industrial Engineering and Engineering Management
Casado-Vara et al., (2018)	Procedia Computer Science	Computer Science
Galvez, et al., (2018)	TrAC - Trends in Analytical Chemistry	Analytical Chemistry
Ge et al., (2017)	Wageningen Economic Research	Economics
Kumar and Iyengar, (2017)	Advanced Science and Technology Letters	Multi-disciplinary
Tian, (2017)	IEEE Access	Electrical and Electronics
Tian, (2016)	IEEE Access	Electrical and Electronics

Appendix C-List of key features identified across the BT literature on AFSC & FASC

Features / Authors	Traceability	Trust/ Privacy	Transparency	Smart contracts	Internet of Things (IoT)	Sustain-ability	Governance	Scalability	Chain of Custody	Barriers in BT adoption	Costs
Akella et al., (2023)	✓	✓	✓						✓		
Bandinelli et al., (2023)	✓		✓						✓		
Karnaushenko et al., (2023)	✓	✓					✓				✓
Peng et al., (2023)	✓	✓	✓	✓			✓				✓
Thompson and Rust, (2023)		✓	✓			✓				✓	
Zhai et al., (2023)	✓	✓	✓								
Meera et al., (2023)								✓		✓	✓

Mileti et al., (2023)	✓					✓	✓				
Liu and Yu, (2023)	✓	✓	✓	✓			✓				✓
Luna et al., (2023)	✓	✓	✓	✓			✓				
Rampone et al., (2023)	✓	✓	✓								
Bager, et al., (2022)	✓								✓		
Tolentino-Zonderva n, et al., (2022)	✓		✓			✓					
Köhler, et al., (2022)		✓				✓	✓				
Olsen *et al.*, (2022)	✓	✓	✓					✓	✓		✓
Khan et al., (2022)	✓	✓	✓	✓							

Bhat *et al.*, (2022)	✓	✓	✓	✓	✓			✓		✓	
Rowan, (2022)	✓	✓				✓					
Song *et al.*, (2022)	✓				✓						✓
Patro et al., (2022)	✓	✓	✓	✓							✓
Patel et al., (2022)	✓	✓	✓					✓			✓
Vu et al., (2022)	✓	✓	✓						✓	✓	✓
Kassanuk and Phasinam, (2022)	✓	✓									
Hu et al., (2021)	✓	✓	✓	✓	✓						✓
Awan *et al.*, (2021)	✓				✓						

Treiblmaier *et al.*, (2021)										✓	
Shew *et al.*, (2021)	✓	✓	✓								✓
Tsolakis *et al.*, (2021)	✓	✓	✓			✓					
Vu et al., (2021)	✓	✓	✓					✓		✓	✓
Demestichas et al., (2020)	✓										
Blaha & Katafono, (2020)	✓	✓	✓							✓	✓
Kayikci *et al.*, (2020)	✓	✓	✓		✓					✓	
Patelli & Mandrioli, (2020)	✓	✓								✓	
Howson, (2020)	✓	✓	✓			✓					
Cruz and da Cruz, (2020)	✓	✓		✓							

Xu, et al., (2020)	✓	✓		✓					✓		
Rejeb *et al.*, (2020)	✓	✓	✓	✓		✓				✓	
Duan et al., (2020)	✓	✓	✓				✓	✓			
Behnke and Janssen, (2020)	✓		✓								
Bumblauskas *et al.*, (2020)	✓										
Kamble, et al., (2020)	✓					✓					
Köhler and Pizzol, (2020)	✓	✓			✓						
Motta et al., (2020)		✓	✓				✓				
Rogerson and Parry, (2020)	✓	✓	✓							✓	
Feng *et al.*, (2020)	✓										

Prashar et al., (2020)	✓		✓			✓					
Qian et al., (2020)	✓										
Xiong *et al.*, (2020)	✓	✓									
Yadav et al., (2020)										✓	
Mirabelli and Solina, (2020)	✓										
Scuderi, et al., (2019)	✓		✓								
Ray *et al.*, (2019)	✓	✓	✓	✓		✓				✓	
Liao and Xu, (2019)	✓	✓	✓			✓					
Pearson *et al.*, (2019)			✓				✓				
Antonucci et al., (2019)	✓		✓								
Surasak et al., (2019)	✓				✓						

Kamble et al.,(2019)	✓	✓	✓	✓			✓	✓			
Salah *et al.*, (2019)	✓	✓					✓	✓			
Montecchi, et al., (2019)	✓	✓	✓								
Creydt and Fischer, (2019)	✓										
Borrero, (2019)	✓	✓	✓								
Basnayake and Rajapakse, (2019)		✓	✓								
Zhao *et al.*, (2019)	✓	✓	✓				✓		✓		
Kamilaris et al., (2019)			✓								
Baralla *et al.*, (2019)		✓									
Mondal *et al.*, (2019)	✓										
Aich *et al.*, (2019)	✓	✓	✓		✓					✓	

Yuxin and Xu, (2019)	✓	✓	✓								✓
Tsang *et al.*, (2019)	✓							✓			
Tripoli and Schmidhuber, (2018)	✓		✓								
Sander, et al., 2018)	✓		✓								
Hua *et al.*, (2018)	✓	✓	✓					✓			
Lucena et al., (2018)	✓	✓	✓	✓		✓					
Lin et al., (2018)	✓	✓									
Mao *et al.*, (2018)		✓									
Caro *et al.*, (2018)		✓	✓								
Tse *et al.*, (2018)	✓	✓				✓	✓				
Casado-Vara *et al.*, (2018)	✓	✓	✓								
Galvez, et al., (2018)	✓		✓								

Ge *et al.*, (2017)	✓	✓				✓					
Kumar and Iyengar, (2017)	✓	✓	✓								
Tian, (2017)		✓	✓								
Tian, (2016)	✓										

Appendix D-In-depth interview questionnaire

DEMOGRAPHICAL INFORMATION	
Gender	M__ F __ Prefer not to say __
Age	_____
Education	Elementary school ____ Secondary school ____ Bachelor's degree ____ Master's degree ____ PhD ____ Other___

Semi-structured interview qualitative schedule – Farmers/Fishers

SPECIFIC OBJECTIVES	QUESTIONS
Introduction & background	• Farm location (region/area), size (n° employee or annual turnover) and activity (e.g., production of shrimp). • Position of the interviewee (e.g., production manager). • For how long you have been working in the fishery and aquaculture sector (e.g., 10 years)? • For how long you have been working in the business (e.g., 5 years)? • Who are your main business partners, which are their roles? (e.g., processors, buyer/collector, fish monger/restaurant owners, wholesaler/retailer, exporter)

Sector challenges and technology	• Which are the current major challenges that are affecting the fishery and aquaculture farming/fishing in India, (if apply) in particular for the shrimp production? (e.g., high cost of energy, lack of transparency, international competition, etc.) • Which could be with the solutions for the mentioned challenges? (e.g., new technologies, more clear regulations, training, etc.) • Could technology help to solve these challenges in the fishery and aquaculture farming/fishing in India, (if apply) in particular for the shrimp production? If, so, which technologies and how? • Are you currently using/considering adoption of new technologies in your business? If "Yes", which technology (e.g., smartphone, etc.), and why you are adopting them (e.g., facilitate transactions)? If "No", why you are not adopting innovative technologies (e.g., expensive)?
Blockchain technology and its adoption	• Have you heard about blockchain technology prior this study? If, "Yes", if "No" (interviewee to briefly describe blockchain technology – Appendix II). • What is your general perception/thoughts about blockchain technology? (e.g., good/bad, etc.), and why? • Do you think blockchain technology can help solve the prior mentioned challenges in your company? If "Yes", which challenges can be solved (e.g., increase trust with distributors) and how (e.g., impossibility to make frauds)? If "No," why?
Benefits and costs of blockchain adoption	Benefits: Supply chain benefits: • Do you think blockchain will increase the trust among supply chain partners (e.g., processors/traders/retailers) due to real-time successful transactions and authenticity of the products supply within the fishery and aquaculture supply chain? If "Yes", why, and how, If "No", why?

	• Do you think that blockchain can reduce transaction costs (e.g., cost needed to find clients) in your company/supply chain? If "Yes", why, and how, If "No", why? • Do you think there would be better coordination among all the supply chain partners due to enhanced end-to-end transparency due to blockchain? If "Yes", why and how, If "No", why? Consumer/market benefits: • Do you think that blockchain may increase consumer trust in the fishery and aquaculture stakeholders due to accessibility to the fish/fish product history (e.g., based on real time data trustworthy data on catch/harvest, processing, transportation, and sustainable certifications). If "Yes", why, and how, If "No", why? • Do you think that the adoption of blockchain can help to access to new clients (e.g., retailers) and/or enter in new markets (e.g., European markets) for fishery and aquaculture stakeholders? If "Yes", why, and how, If "No", why? Regulatory benefits: • Do you think blockchain will reduce the frequency of seafood frauds (e.g., product mislabeling, species substitution, IUU frauds etc.). If "Yes", why, and how, If "No", why? • Do you think the adoption of blockchain will help to meet and anticipate future regulations from Governments or standard requested by processors, traders, or retailers (e.g., more stringent traceability, labeling regulations)? If "Yes", why, and how, If "No", why? • Do you think blockchain will improve food safety compared to the current state (e.g., real-time monitoring to maintain the ideal temperature throughout the supply chain)? If "Yes", why and how, If "No", why? • Do you think blockchain technology will bring more efficiency in recalls management and/or reduce them? (e.g., reduced time in the identification of

	lot and real time recall of bad quality product). If "Yes", why and how, If "No", why? **Costs:** • Do you think that the implementation of blockchain in your company will have high implementation cost (e.g. software development, installation, certification, and integration with current software costs)? If "Yes", which one and why, If "No", why? • Do you think that the implementation of blockchain in your company will have high operations costs (e.g. rent, utilities, insurance, maintenance and repairs, and advertising, certification)? If "Yes", which one and why, If "No", why?
Conclusions and recommendations	• Do you have any suggestions or recommendations about the adoption of blockchain in fishery and aquaculture farming/fishing in India, (if apply) in particular for the shrimp production in India? • Is there anything more you would like to add? • Thank you for your time.

Semi-structured interview protocol – Processors

SPECIFIC OBJECTIVES	QUESTIONS
Introduction & background	• Company name, location (region/area), size (n° employee or annual turnover) and activity (e.g., processing of shrimp). • Position of the interviewee (e.g., production manager).

	• For how long you have been working in the fishery and aquaculture sector (e.g. 10 years)? • For how long you have been working in the company (e.g., 5 years)? • Who are your main business partners, which are their roles? (e.g., processors, buyer/collector, fish monger/restaurant owners, wholesaler/retailer, exporter)
Sector challenges and technology	• Which are the current major challenges that are affecting the fishery and aquaculture processing in India, (if apply) in particular for the shrimp processing? (e.g., high cost of energy, lack of transparency, international competition, etc.) • Which could be with the solutions for the mentioned challenges? (e.g., new technologies, more clear regulations, etc.) • Could technology help to solve these challenges in the fishery and aquaculture processing in India, (if apply) in particular for the shrimp processing? If so, which technologies and how? • Are you currently using/considering adoption of technology in your business? If "Yes", which technology (e.g., smartphone, etc.), and why you are adopting them (e.g., facilitate transactions)? If "No", why you are not adopting new technologies (e.g., expensive)?
Blockchain technology and its adoption	• Have you heard about blockchain technology prior this study? If, "Yes", if "No" (interviewee to briefly describe blockchain technology-Annex I). • What is your general perception/thoughts about blockchain technology? (e.g., good/bad, etc.), and why? • Do you think the blockchain technology can help solving the prior mentioned challenges in your company? If "Yes", which challenges can be solved (e.g., increase trust with distributors) and how (e.g., impossibility to make fraud/s)? If "No", why?

Benefits and costs of blockchain adoption	Benefits: Supply chain benefits: • Do you think blockchain will increase the trust among supply chain partners due to real-time successful transactions and authenticity of the products supply within the fishery and aquaculture supply chain? If "Yes", why and how, If "No", why? • Do you think that blockchain can reduce transaction costs (e.g., cost needed to find clients) in your company/supply chain? If "Yes", why and how, If "No", why? • Do you think there would be a better coordination among all the supply chain partners due to enhanced end-to-end transparency due to blockchain? If "Yes", why and how, If "No", why? Consumer/market benefits: • Do you think that blockchain may increase consumer trust in the fishery and aquaculture stakeholders due to accessibility to the fish/fish product history (e.g., based on real time data trustworthy data on catch/harvest, processing, transportation, and sustainable certifications). If "Yes", why and how, If "No", why? • Do you think that the adoption of blockchain can help to access to new clients (e.g., retailers) and/or new markets (e.g., European markets) for fishery and aquaculture stakeholders? If "Yes", why and how, If "No", why? Regulatory benefits: • Do you think blockchain will reduce the frequency of seafood frauds (e.g., product mislabeling, species substitution, IUU frauds etc.). If "Yes", why and how, If "No", why? • Do you think the adoption of blockchain will help to meet and anticipate future regulations from Governments or standard requested by processors, traders or

	retailers (e.g., more stringent traceability or labeling regulations)? If "Yes", why and how, If "No", why? • Do you think blockchain will improve food safety compared to the current state (e.g., real-time monitoring to maintain the ideal temperature throughout the supply chain)? If "Yes", why and how, If "No", why? • Do you think blockchain technology will bring more efficiency in recalls management and/or reduce them? (e.g., reduced time in the identification of lot and real time recall of bad quality product). If "Yes", why and how, If "No", why? Costs: • Do you think that the implementation of blockchain in your company will have high implementation cost (e.g. software development, installation, and integration with current software costs)? If "Yes", which one and why, If "No", why? • Do you think that the implementation of blockchain in your company will have high operations costs (e.g. such as rent, utilities, insurance, maintenance and repairs, and advertising)? If "Yes", which one and why, If "No", why?
Conclusions and recommendations	• Do you have any suggestions or recommendations about the adoption of blockchain in fishery and aquaculture processing in India, (if apply) in particular for the shrimp processing in India? • Is there anything more you would like to add? Thank you for your time.

Semi-structured interview protocol-Distributors/Retailers/Merchants/Exporters

SPECIFIC OBJECTIVES	QUESTIONS
Introduction & background	• Company name, location (region/area), size (n° employee or annual turnover) and activity (e.g., distribution of shrimp). • Position of the interviewee (e.g., buyer manager). • For how long you have been working in the fishery and aquaculture sector (e.g., 10 years)? • For how long you have been working in the company (e.g., 5 years)? • Who are your main business partners? (buyer/collector, fish monger/restaurant owners, wholesaler/retailer, exporter)
Sector challenges and technology	• Which are the current major challenges that are affecting fishery and aquaculture sector in India, (if apply) in particular for the shrimp supply chain? (e.g., high cost of energy, lack of transparency, international competition, fish frauds etc.) • Which could be with the solutions for the mentioned challenges? (e.g., new technology, more clear regulations, etc.) • Are you currently using/considering adoption of technology in your business? If "Yes", which technology, and why? If "No", why you are not adopting new technologies?
Blockchain technology and its adoption	• Have you heard about blockchain technology prior this study? If, "Yes", if "No" (interviewee to briefly describe – Annex I). • What is your general perception/thoughts about blockchain technology? (e.g., good/bad, etc.), and why? • Do you think this blockchain technology can help solving the mentioned challenges in your company and distributors of fish/shrimps, in general? If "Yes", which challenges and how? If "No", why?

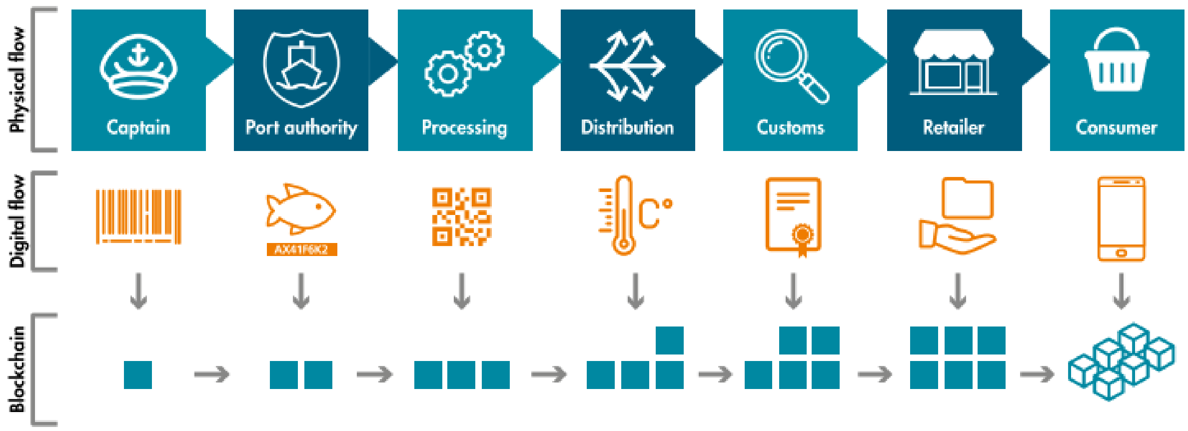
Benefits and costs of blockchain adoption	Benefits: Supply chain benefits: • Do you think blockchain will increase the trust among supply chain partners due to real-time successful transactions and authenticity of the products supply within the fishery and aquaculture supply chain? If “Yes”, why, and how, If “No”, why? • Do you think that blockchain can reduce transaction costs (e.g., cost needed to work with suppliers) in your company/supply chain? If “Yes”, why, and how, If “No”, why? • Do you think, there would be a better coordination among all the supply chain partners due to enhanced end-to-end transparency due to blockchain? If “Yes”, why, and how, If “No”, why? Market benefits: • Do you think that blockchain may increase consumer trust in the fishery and aquaculture stakeholders due to accessibility to the fish/fish product history (e.g., based on real time data trustworthy data on catch/harvest, processing, transportation, and sustainable certifications)? If “Yes”, why, and how, If “No”, why? • Do you think that the adoption of blockchain can help to access to new clients (e.g., retailers) and/or new markets (e.g. European markets) for fishery and aquaculture stakeholders? If “Yes”, why, and how, If “No”, why? Regulatory benefits: • Do you think blockchain will reduce the frequency of seafood frauds (e.g., product mislabeling, species substitution, IUU frauds etc.). If “Yes”, why, and how, If “No”, why? • Do you think the adoption of blockchain will help to meet and anticipate future regulations from Governments or standard requested by processors, traders, or retailers (e.g., more stringent traceability or labeling regulations)? If “Yes”, why, and how, If “No”, why?

	• Do you think blockchain will improve food safety compared to the current state (e.g., real-time monitoring to maintain the ideal temperature throughout the supply chain)? If "Yes", why and how, If "No", why? • Do you think blockchain technology will bring more efficiency in recalls management and/or reduce them? (e.g., reduced time in the identification of lot and real time recall of bad quality product). If "Yes", why and how, If "No", why? **Costs:** • Do you think that the implementation of blockchain in your company will have high implementation cost (e.g., software development, installation, and integration with current software costs)? If "Yes", which one and why, If "No", why? • Do you think that the implementation of blockchain in your company will have high operations costs (e.g., such as rent, utilities, insurance, maintenance and repairs, and advertising)? If "Yes", which one and why, If "No", why?
Conclusions and recommendations	• Do you have any suggestions or recommendations about the adoption of blockchain in fishery and aquaculture farming/fishing in India, (if apply) in particular for the shrimp production in India? • Is there anything more you would like to add? Thank you for your time.

Appendix E- What is a Blockchain technology?

Blockchain Technology (BT) could be defined as an encrypted digital ledger which is stored on several computers in a public or private network. BT consist of data records called as blocks. Each transaction occurred, is put into a block, whereas each of it is connected to the previous and the next block simultaneously. In this similar fashion an irreversible chain of blocks and transactions are blocked together – forming a "blockchain". The blocks forming a chain, cannot be altered, or erased by any participant. The bigger is the network, the stronger and immutable (tamper-resistant) the BT will become.

Thus, this decentralised and distributed ledger of the stored data reduces the threat of single point access failure as in the centralized network model. Hence the uneven structure of the information stored in the smart contracts feature of BT have a check on harmful attacks securing the information which assures the genuine and inclusive nature of the data. Following is a diagrammatic representation (Figure 15) of BT enabled fish supply chain.



(Source:Blaha & Katafono, 2020)

Figure 15- Blockchain in fisheries & aquaculture supply chain

Appendix F-Particiapation Information Sheet

Reference number:

Participant Information Sheet

Project title: *Stakeholders Perceptions of Blockchain Adoption in The Fishery and Aquaculture Supply Chain in India*

I am a PhD student at the University of Reading. This interviews forms part of my thesis which will contribute to my doctorate.

This research aims to find out the beliefs and perceptions of stakeholders such as fishers/farmers, processors/ retailers/exporters/ Merchants/ Distributers in adopting blockchain technology in the fisheries and aquaculture supply chain. I am interested in exploring the sector challenges, and the challenges, benefits, and costs of blockchain adoption in the fisheries and aquaculture supply chain.

To undertake this research, I am currently contacting you and would like to invite you to participate in an in-depth interview taking place via online (MS Teams/google meet/Zoom) or by phone or face-to-face at your official/farm location which will take approximately 25-30 min. of your time.

I have selected participants who are one of the fisheries and aquaculture supply chain stakeholders from India. You must be 18 or older to participate in the study and a fishery and aquaculture supply chain stakeholders dealing with Indian fish products. You are encouraged to freely express your opinions and please be assured that your views are valued and that there are no right or wrong answers to the questions asked. We will not collect any names or personal details as part of the interview. Individual results will be kept confidential between myself and my supervisors. Questions on demographic details (for example your age and status) are asked where it is helpful to analyse data.

The raw data will be kept on my personal computer, which is password protected, and will only be accessed by myself and my supervisor and will not be shared with third parties. The data will be destroyed at the end of my doctorate in April 2024.

Your participation is entirely voluntary, and you are free to withdraw from the interview at any time you feel uncomfortable or unwilling to participate, and you do not have to specify a reason. Any in-part or total contribution can be withdrawn up until the point at which the data is aggregated before/on 30/06/2022. After/on 30/06/2022 it will not be possible to withdraw your contribution from the results of the research. If you wish to withdraw, please contact a.gawai@pgr.reading.ac.uk. The reference number at the top of the page will only be used to identify your questionnaire/interview transcript and will not reveal any other information about you.

The discussion will be audio or video recorded if you agree, and the anonymised transcripts of the audio/video recordings will be used by myself and supervisors. Once transcribed the original recording will be deleted. Your anonymity will not be compromised as only the reference number above will be used to identify the transcript. The findings will be written up into my thesis/published in academic journals.

If at any stage, you wish to receive further information about this research project please to not hesitate to contact a.gawai@pgr.reading.ac.uk before 30/04/2024.

By participating in this interview, you are acknowledging that you understand the terms and conditions of participation in this study and that you consent to these terms.

This research project has been reviewed according to the procedures specified by the University Research Ethics Committee and has been given a favourable ethical opinion for conduct.

Thank you very much for taking time to take part in this interview!

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Appendix G-Questionnaire consumer preferences for shrimp

This study is being conducted by researchers from the University of Reading (United Kingdom). The purpose is to investigate consumer preferences for shrimps. You are being asked to participate in a research project by taking an online survey. You must be 18 or older, live in the United States, be responsible for more than half of your household food purchase, and purchase shrimp at least once every six months to participate in the survey. The online survey should not take more than 15 minutes of your time. Please remember that once you have answered the question, you cannot go back, thus choose the answer carefully. You can be assured that your answers will be kept confidential and will only be released as summaries. Your name will not be collected as part of your survey response, and thus can never be associated with the data. Your responses are strictly voluntary and they will not be individually identified or publicized. You will not be qualified for an incentive if you drop out of the survey or give poor quality data.

In the following screen you will find your unique ID code. Please save it and use it to address yourself if you wish to inform us about your intent to withdraw from the study after completing survey by contacting the researcher Aniket Gawai at: *a.gawai@pgr.reading.ac.uk* until when the data is aggregated on 30/06/2023. If you decide to withdraw, you would still be qualified for your incentive if the survey is deemed as successfully completed on our conclusion.

The submitted data will be used for statistical purposes only and statistical results will be reported in research papers, conferences, academic journals, and as examples of teaching. There are no anticipated risks in participating in this study. By participating in this survey, you will contribute to research on a better understanding of consumer preferences for shrimps that in turn can inform the economy and public policy.

This application has been reviewed according to the procedures specified by the University of Reading Research Ethics Committee and has been given a favorable ethical opinion for conduct. If you have questions about your rights as a participant, you may contact the University of Reading - School of Agriculture Policy and Development Ethics Committee, Email: sapdethics@reading.ac.uk.

If you have questions at any time about the study or the procedures, (or you experience adverse effects as a result of participating in this study) you may contact us at: *a.gawai@pgr.reading.ac.uk*. Clicking the button to continue will be considered your consent to participate. Thank you very much for taking time to participate in this survey!

ID code

Your unique ID code is: ______________________

Icebreaker question 1

Q1. We care about the quality of our survey data and hope to receive the most accurate measures of your opinions, so it is important to us that you thoughtfully provide your best answer to each question in the survey.

Do you commit to providing your thoughtful and honest answers to the questions in this survey?

- I will provide my best answers.
- I will not provide my best answers.
- I can't promise either way.

NOTE for the researcher: only consumers who indicate "*I will provide my best answers*" will continue with the survey.

Icebreaker question 2

Q2. In which country do you currently live?

List of countries:________________________

NOTE for the researcher: Only consumers who selected *"United States"* will continue with the survey.

Icebreaker question 3

Q3. What is your gender?

- Female
- Male
- Prefer not to say

Icebreaker question 4

Q4. How old are you? ______*years*

NOTE: only consumers of years: 18+ will continue with the survey.

Icebreaker question 5

Q5. Please indicate your approximate annual household income before taxes:

- Less than $10,000
- $10,000 - $19,999
- $20,000 - $29,999
- $30,000 - $39,999
- $40,000 - $49,999
- $50,000 - $59,999
- $60,000 - $69,999
- $70,000 - $79,999
- $80,000 - $89,999
- $90,000 - $99,999
- $100,000 - $149,999
- $150,000 or more
- I do not know/I do not want to declare.

Icebreaker question 6

Q6. Are you fully or partially responsible for food purchases of your household?

- I am primarily responsible for food purchase.
- I am responsible for more than half of food purchases.
- I am responsible for less than half of food purchases.
- I am not responsible for food purchases.

NOTE for the researcher: only consumers who indicate "*I am primarily responsible for food purchase*" or "*I am responsible for more than half of food purchases*" will continue with the survey.

Icebreaker question 7

Q7. How frequently do you purchase shrimp at the store?

Never	c
Less than once every 6 months	c
Once every 6 months	c
Once between 3 to 6 months	c
Once between 1 to 3 months	c
Once a month	c
2-3 times a month	c
Once a week	c
Twice a week	c
3-4 times a week	c
5-6 times a week	c
Everyday	c

NOTE for the researcher: consumers who indicate "*Never*" or "*Less than once every 6 months*" will not continue with the survey.

<u>Please read the following information carefully. You will be able to press the button to continue only after 20 seconds.</u>

Definitions

On the following screens you will see a series of **shrimp** packages. **All** the **products are identical** and **adhere** to the same **food safety standards, regulations** and have the **same characteristics** (e.g. taste, colour, size, origin, brand, etc.) except for the **blockchain certification**, **antibiotic use**, **QR code**, and **price**.

Now, we will explain the **different characteristics** of the shrimp packages in details:

1. **Blockchain certification**: Blockchain is a digital technology ledger that is decentralized shared, programmable, and cryptographically secure. Each record on a blockchain is agreed upon by all members of the network, and then it becomes a permanent record that cannot be altered. Thus, blockchain is a trusted digital technology ledger which no single user controls and which can be inspected by anyone. In short, blockchain is a digital technology ledger which ensures that information reported on the package label of shrimp (e.g. country of origin, nutritional information, producer name, etc.) is true because it cannot be altered or erased by any food businesses (e.g. farmers, fishers, processors, exporters, importers, government food safety agencies, wholesalers, retailers, etc.) involved in the shrimp supply chain from the farm to the consumer. On the product you will find information presented in two ways:
   - *With Blockchain certified label:* the blockchain certified label indicates that the food businesses (e.g. farmers, fishers, processors, exporters, importers, government food safety agencies, wholesalers, retailers, etc.) involved in the shrimp supply chain are using the blockchain technology.
   - *No label is reported*.

2. **Antibiotics use**: it refers to the fact that antibiotics might be used during the shrimp production. On the product you will find information presented in two ways:
   - With information saying *"No antibiotics ever"* meaning that no antibiotics were ever used in any process of the shrimp production.
   - *No information is reported.*

3. **QR code:** it refers to a sticker reported on the package of shrimps that can be scanned by a device (e.g. mobile phone, etc.) which allows consumers to visit the Internet website (e.g. website of the producer) that provides information about the shrimp history (e.g. type of shrimp, producer name, country of origin, sustainability standards, nutritional information, etc.). On the product you will find information presented in two ways:

- *With the QR-code*: it means that information about the shrimp history (e.g. type of shrimp, producer name, country of origin, sustainability standards, nutritional information, etc.) contained in the Internet website (e.g., website of the producer) can be accessed by consumers.
- *No QR-code is reported.*

4. **Price**: it refers to the price in $/lb of shrimps. There will be four price levels.

Script

BEFORE YOU PROCEED, PLEASE TAKE TIME TO CAREFULLY READ THE FOLLOWING INSTRUCTIONS

<u>Please read the following information carefully. You will be able to press the button to continue only after 20 seconds.</u>

Imagine **you are** in your **usual supermarket** and **considering** the **purchase of a package of raw, frozen, jumbo size, and 16 oz (1 lb.) shrimps**. In the following screens, **you will see** a **series choice questions**. **Each choice question** includes a **description** of **two different shrimp packages**. **All features** of the **products** in each choice question **are identical except** that they **vary** in terms of the **blockchain certification**, **antibiotic use**, **QR code**, and **price**. In **each choice question**, please **indicate** the **shrimp package** that **you would choose to purchase**. **Alternatively**, you may **choose NOT TO PURCHASE either product**.

Please **carefully examine each option before** you **make a decision** and **select the decision** that you would make **based on your own preferences**. Previous similar studies show that people often respond in one way but act differently. In studies where people do not actually have to pay money for a product when indicating a particular preference, people state a higher willingness to pay than what one actually is willing to pay for the good in the store. A possible reason for this is that people do not really consider how large the impact of this extra cost actually is on the available family budget. It is easy to be generous when you do not really have to pay for it. In the store, people might think in a different way: the amount of money spent on this good cannot be spent on other things. **<u>We ask you to respond to each of the following choice questions just exactly as you would if you were in a real store and had to pay for your choice</u>**. Please keep this in mind when answering the following choice questions.

IMPORTANT:

CHOOSE one of the **options on each page**. **Or** you **may choose "*I would not buy either option A or B*".**

- **Assume** that the **options** on each page **are** the **only ones available**.
- **Do not compare options** on **different pages.**

You might see a **few options** that **may seem counter-intuitive** (e.g. a lower price, but a higher quality in your personal opinion). Be assured that this **is not an error**, but **part of the design of the survey**. Simply **choose** the **option** in each choice question that **you prefer the most**, based on its characteristics.

Quality control question

Q8. Before proceeding to the next set of questions, we want to ask for your feedback about the responses you provided so far. It is vital to our study that we only include responses from participants who devoted their full attention to this study. In your honest opinion, should we use your responses, or should we discard your responses since you did not devote your full attention to the questions so far?

- Yes, I have devoted full attention to the questions so far and I think you should use my responses for your study.
- No, I have not devoted full attention to the questions so far and I think you should not use my responses for your study.

NOTE for the researcher: consumers who indicate "*No, I have not devoted full attention to the questions so far and I think you should not use my responses for your study*" will not continue with the survey.

Q9. Which type of device are you using for this survey?

- Personal computer (PC) or tablet
- Mobile phone

TREATMENT 1 – CONTROL (Only general information is provided) – N = 200 consumers

"Please proceed to the next page".

TREATMENT 2 – FOOD FRAUD BENEFITS – N = 200 consumers. We will provide the following statement:

Please read the following information carefully. You will be able to press the button to continue only after 20 seconds.

"By purchasing shrimps with the blockchain certified label it ensures a reduced number of frauds about the product (e.g. wrong country of origin, mislabelling, product substitution, etc.) due to the end-to-end visibility from the farm to the retail store."

SCREEN 14

TREATMENT 3 – FOOD SAFETY BENEFITS – N = 200 consumers. We will provide the following statement:

Please read the following information carefully. You will be able to press the button to continue only after 20 seconds.

"By purchasing shrimps with the blockchain certified label it ensures an improved food safety of the product (e.g. better prevention from food-borne pathogens contaminations, free from chemicals, allergens, antibiotics, etc.) due to the end-to-end visibility from the farm to the retail store."

TREATMENT 4 – SUSTAINABILITY BENEFITS – N = 200 consumers. We will provide the following statement:

<u>Please read the following information carefully. You will be able to press the button to continue only after 20 seconds.</u>

"By purchasing shrimps with the blockchain certified label it ensures an improved sustainable production meaning that the production of shrimps has met with the Best Aquaculture practices standards (i.e. improve aspects related to environment, social responsibility, animal welfare, food safety, and traceability) due to the end-to-end visibility from the farm to the retail store."

Example: Choice set 1

Q10-17. Imagine you are in a store, and you would like to purchase a package of raw, frozen, and jumbo size shrimps. Do you choose Option A, Option B or Option C?

Attribute Non-Attendance 1

Now, we will ask you a few questions about the attributes that you have considered when you made your choices.

Q18. While responding to the choice questions, did you ignore (i.e. not consider) any of the attribute/label information (i.e. blockchain certification, antibiotic use, QR code, and price) reported on the shrimp packages (label)?

- Yes
- No

<u>**NOTE for the researcher: only consumers who ticked "*Yes*" in question 18 will continue with question 18.1, while the others (i.e. who responded "*No*") will continue with question 19.**</u>

Attribute Non-Attendance 2

Q18.1 Which of the following attributes did you ignore (i.e. not consider)? Please, check all that apply.

- Blockchain certification
- Antibiotics use
- QR code
- Price

Awareness about blockchain technology 1

Q19. Have you ever heard of the term "blockchain" prior to participating in this survey?

- Yes
- No

<u>**NOTE: only consumers who ticked "*Yes*" in question 19 will continue with question 19.1, while the others (i.e. who responded "*No*") will continue with the question 20.**</u>

Awareness about blockchain technology 2

Q19.1. From 1 (Very low knowledge) to 7 (Very high knowledge), how much did you know about "blockchain" prior to participating in this survey?

- 1 - Very low knowledge
- 2
- 3
- 4
- 5
- 6
- 7 - Very high knowledge

Blockchain technology use

Q20. The following statements deal with perception about blockchain use. Please give us your opinion on the following statements:

	Strongly disagree 1	**2**	**3**	**4**	**Strongly agree 5**
I would find blockchain technology useful in my daily life.	c	c	c	c	c
Blockchain technology would help me with my choices of shrimp purchases.	c	c	c	c	c
Blockchain technology would help me be more efficient with my shrimp shopping.	c	c	c	c	c
Learning how to use blockchain technology to trace shrimps would be easy for me.	c	c	c	c	c
The use of blockchain technology would make me easy to understand the traceability of shrimps.	c	c	c	c	c
The use of blockchain technology would make me easier to detect the authenticity of shrimps.	c	c	c	c	c

Technology readiness

Q21. We are interested in your views on how technology influences your life. Please indicate how much you agree with the following statements.

	Strongly disagree 1	**2**	**3**	**4**	**Strongly agree 5**
New technologies contribute to a better quality of life	c	c	c	c	c
Technology gives me more freedom of mobility	c	c	c	c	c
Technology gives people more control over their daily lives	c	c	c	c	c
Technology makes me more productive in my personal life	c	c	c	c	c
Other people come to me for advice on new technologies	c	c	c	c	c
In general, I am among the first in my circle of friends to acquire new technology when it appears	c	c	c	c	c
I can usually figure out new high-tech products and services without help from others	c	c	c	c	c
I keep up with the latest technological developments in my areas of interest	c	c	c	c	c

When I get technical support from a provider of a high-tech product or service, I sometimes feel as if I am being taken advantage of by someone who knows more than I do	c	c	c	c	c
Technical support lines are not helpful because they don't explain things in terms I understand	c	c	c	c	c
Sometimes, I think that technology systems are not designed for use by ordinary people	c	c	c	c	c
There is no such thing as a manual for a high-tech product or service that's written in plain language	c	c	c	c	c
People are too dependent on technology to do things for them	c	c	c	c	c
Too much technology distracts people to a point that is harmful	c	c	c	c	c
Technology lowers the quality of relationships by reducing personal interaction	c	c	c	c	c
I do not feel confident doing business with a place that can only be reached online	c	c	c	c	c

Food values

Q22. The following statements deal with the importance of different attributes when buying food.

Please give us your opinion on the following attributes:

	Not important at all 1	**2**	**3**	**4**	**5**	**6**	**Extremely Important 7**
Taste (extend to which consumption for the food is appealing to the senses)	c	c	c	c	c	c	c
Naturalness (extent to which food is produced without modern technologies)	c	c	c	c	c	c	c
Price (the price that is paid for the food)	c	c	c	c	c	c	c
Safety (extent to which consumption of food will not cause illness)	c	c	c	c	c	c	c
Convenience (ease with which food is cooked and/or consumed)	c	c	c	c	c	c	c
Nutrition (amount and type of fat, protein, vitamins, etc.)	c	c	c	c	c	c	c
Tradition (preserving traditional consumption patterns)	c	c	c	c	c	c	c

Origin (where the agricultural commodities were grown)	c	c	c	c	c	c	c
Fairness (the extent to which all parties involved in the production of the food equally benefit)	c	c	c	c	c	c	c
Appearance (extent to which food looks appealing)	c	c	c	c	c	c	c
Environmental impact (effect of food production on the environment)	c	c	c	c	c	c	c
Traceability (ability to follow the movement of a food product and its ingredients through all steps in the supply chain, both backward and forward)	c	c	c	c	c	c	c

Shrimp purchasing habits 1

Q23. Which type of shrimp do you purchase most frequently?

	Never 1	**Sometimes 3**	**Often 4**	**Always 5**
Fresh & Raw	c	c	c	c
Frozen & Raw	c	c	c	c
Fresh & Cooked	c	c	c	c
Frozen & Cooked	c	c	c	c
Others, please specify: _______________	c	c	c	c

Shrimp purchasing habits 2

Q24. How important are the following criteria when buying shrimps?

	Not important at all 1	**2**	**3**	**4**	**5**	**6**	**Extremely Important 7**
Country of origin	c	c	c	c	c	c	c
Nutritional information	c	c	c	c	c	c	c
Type of ingredients	c	c	c	c	c	c	c

Size of the shrimp (e.g. X-large, etc.)	c	c	c	c	c	c	c
Package weight (i.e. lb)	c	c	c	c	c	c	c
Count shrimp per pound	c	c	c	c	c	c	c
Shelf life (e.g. Best by…)	c	c	c	c	c	c	c
Name of the producers/ distributors/sellers	c	c	c	c	c	c	c
Brand	c	c	c	c	c	c	c
Price	c	c	c	c	c	c	c
Production method (i.e. wild caught, farm raised)	c	c	c	c	c	c	c
Colour of the shrimps	c	c	c	c	c	c	c
Sustainability certifications (e.g. BAP-best aquaculture practices)	c	c	c	c	c	c	c
Variety of shrimp (e.g. White leg, Black tiger etc.)	c	c	c	c	c	c	c
Shrimp characteristics (e.g. peeled, deveined, tail-on, etc.)	c	c	c	c	c	c	c
Food safety (e.g. no preservatives, no chemicals, etc.)	c	c	c	c	c	c	c
Instructions on manipulation (e.g. how to thaw, frozen, etc.)	c	c	c	c	c	c	c
Others, please specify: ________________	c	c	c	c	c	c	c

Trust 1

Q25. In general, how much is important the trust (i.e. the believe that someone is good and honest and will not harm you, or that something is safe and reliable) in the food chain (i.e. farmers, processors, exporters, importers, wholesalers, and retailers) for you?

Not important at all 1	2	3	4	5	6	Extremely Important 7
c	c	c	c	c	c	c

Trust 2

Q26. In general, how much do you trust (i.e. the believe that someone is good and honest and will not harm you, or that something is safe and reliable) the food chain (i.e. farmers, processors, exporters, importers, wholesalers, and retailers)?

I do not trust at all 1	2	3	4	5	6	Extremely trust 7
c	c	c	c	c	c	c

Transparency 1

Q27. In general, how much is important the transparency (i.e. the quality of being done in an open way without secrets) in the food chain (i.e. farmers, processors, exporters, importers, wholesalers, and retailers) for you?

Not important at all 1	2	3	4	5	6	Extremely Important 7
c	c	c	c	c	c	c

Transparency 2

Q28. In general, how much do you think the food chain (i.e. farmers, processors, exporters, importers, wholesalers, and retailers) is transparent (i.e. the quality of being done in an open way without secrets)?

Not transparent at all 1	2	3	4	5	6	Extremely transparent 7
c	c	c	c	c	c	c

Socio – demographic information 1

Q29. How many individuals live in your household where you currently reside, including yourself?

______

Socio – demographic information 2

Q30. Are children under the age of 18 present in the household?

- Yes
- No

Socio – demographic information 3

Q34. What is your educational background? Please, mark the box next to the highest level of education you have completed.

- Elementary/Some High School
- High School Diploma
- Some college
- Technical School Diploma
- Associate degree
- Bachelor's Degree
- Master's Degree
- Doctorate
- Other, please specify:________________________

Thank you!

If you have any comments regarding this survey, please enter them in the box

Appendix H- TRAM framework constructs and their measurement

Variables	Codes	Measurement items	Sources
Perceived usefulness	PU1	I would find blockchain technology useful in my daily life.	(Davis, 1989)
	PU2	Blockchain technology would help me with my choices of shrimp purchases.	
	PU3	Blockchain technology would help me be more efficient with my shrimp shopping.	
	EU1	Learning how to use blockchain technology to trace shrimps would be easy for me.	(Davis, 1989),

Perceived ease of use	EU3	The use of blockchain technology would make me easy to understand the traceability of shrimps.	(V. Venkatesh & Davis, 2000)
	EU3	The use of blockchain technology would make me easier to detect the authenticity of shrimps.	
Optimism	OP1	Blockchain technology can contribute to a better quality of food	(Ariani et al., 2018; Parasuraman & Colby, 2014; Salari, 2022; Salim et al., 2022)
	OP2	Blockchain technology will give people more freedom of food choice	
	OP3	Blockchain technology will give people more control over their daily food buying habits	
Innovativeness	IN1	Blockchain technology will makes people more efficient to check the quality of food	
	IN2	If blockchain technology becomes available, I will be among the first in my circle of friends to acquire new technology when it appears	
	IN3	If blockchain technology becomes available, I can usually figure out it and its services without help from others	
Discomfort	D1	I think that blockchain technology is not designed for use by ordinary people	
	D2	Blockchain technology will increase the dependence of people on technology to do things for them	
Insecurity	IS1	Blockchain technology will distracts people to a point that is harmful for them	
	IS2	Blockchain technology will lower the quality of relationships among people by reducing personal interaction	

Appendix I-Summary statistics of TRAM model

					Correlation co-efficient					
TRAM constructs	***Mean***	***Standard Deviation***	***Skewness***	***Kurtosis***	***PU***	***EU***	***OPT***	***INN***	***INS***	***DIS***
					Co-efficient (p-value)					
Perceived Usefulness (PU)	3.50	0.97	-0.68	3.14	1.00					
Ease of Use (EU)	3.73	0.85	-0.86	3.89	0.79 (0.00)	1.00				
Optimism (OPT)	3.85	0.75	-0.90	4.48	0.41 (0.00)	0.43 (0.00)	1.00			
Innovativeness (INN)	3.34	0.94	-0.36	2.49	0.33 (0.00)	0.35 (0.00)	0.60 (0.00)	1.00		
Insecurity (INS)	2.82	0.78	0.07	2.88	-0.09 (0.00)	-0.16 (0.00)	-0.25 (0.00)	-0.25 (0.00)	1.00	
Discomfort (DIS)	3.22	0.87	-0.39	2.85	-0.18 (0.00)	-0.19 (0.00)	-0.40 (0.00)	-0.35 (0.00)	0.57 (0.00)	1.00