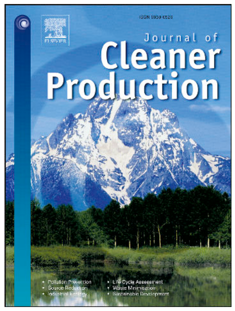

Enablers to achieve zero hunger through IoT and blockchain technology and transform the green food supply chain systems

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Enablers to Achieve Zero Hunger Through IoT and Blockchain Technology and Transform the Green Food Supply Chain Systems

Abstract

Food security necessitates a multifaceted strategy, ranging from social protection to providing healthy food. Change in existing food systems is needed to create a more equitable and sustainable society. Hunger is one of the significant challenges in the world that arise due to food insecurity, bad quality, food waste, and losses that leads to damage of public health. The implementation of green food supply chain management (GFSCM) practices in the food supply chain helps in lowering food wastage, carbon emissions, food quality, and safety. To strengthen food security/safety and quality, digital transformation of the supply chain is required, and IoT and blockchain can help in achieving this. Digital transformation of GFSCM has helped to improve food security, safety and quality control. This study identifies modern enablers of food security, safety and quality that transform the GFSCM through Internet of things (IoT) and blockchain to reduce hunger. Zero hunger goal is far behind in India as India reported 117th rank in hunger index, indicating an urgent need to study the digital transformation in green food supply chain towards achieving food quality and security. In this study twelve enablers out of 16 suggested in earlier literatures has been selected and reconfirmed with the feedback of seventeen academia and Industrial experts from Indian food supply chain. We used a two-step combined Interpretive Structural Modeling (ISM) and Analytical Network Process (ANP) technique to examine the enablers contextual interrelationships and significance weights. Findings reveal that IoT and blockchain technologies are the main actuators of the contemporary GFSCM enabling system. ISM provides eight core enablers system that can transform the GFSCM digitally to achieve food quality and security along with achieving zero hunger (SDG2). Inventory management is the least ranked enabler, whereas IoT and blockchain are the top two. Towards achieving zero hunger, some management, theoretical, and policy implications have been suggested.

Keywords: *Sustainable Development Goals; Green Food Supply Chain; Zero hunger; Internet of Things (IoT)- Blockchain; Interpretive structural modeling (ISM)-Analytical network process (ANP)*

1. Introduction

Recent research that evaluated the Covid-19 scenario in 2020 revealed significant failures, with an increase in the number of people facing hunger and food insecurity as the big crisis increased inequities that had already hampered development before the pandemic (Trollman et al., 2021). Food insecurity, food fraud, poor quality of food distribution, and food waste generated has raised environmental concerns. The green food supply chain management (GFSCM) concept has come into the picture to reduce the waste generated and the negative environmental consequences as it focused on utilizing green resources throughout the supply chain operations and aims to achieve carbon neutrality (Luo et al., 2022). In the current situation, FSCs have challenges in lowering carbon emissions by implementing green practices (Luo et al., 2022). Furthermore, in the recent era of the digitalization industry 4.0 (I4.0) technologies are utilized to support the GFSCM for improving food security and quality (Kayikci et al., 2022). In the food sector, the IoT and blockchain technology are the most commonly practiced for food security purposes. Blockchain technology provides security through enhancing traceability, while IoT works as a support system (Trollman et al., 2022). For the modernization of the supply chain, this study identifies GFSCM enablers for food security improvement through IoT and blockchain technology. The modern technology-based GFSCM enablers help in achieving sustainable development goals (SDG) like zero hunger (SDG2) and good health and wellbeing (SDG3) because of ensuring food security.

FSC comprises food producers (farmers), manufacturers (processing facilities), warehouses, distributors, retailers, and customers, and all work together to meet the customers demand (Demestichas et al., 2020; Kumar & Choubey, 2022). Every party of the supply chain bears the same duty to deliver safe, secure, and good-quality food. As the number of processes rises, so do concerns about food security because of food tampering and fraud (Onyeaka et al., 2022). Consumers are more devoted to food quality and safety (FQS) (van Rijswijk & Frewer, 2008). However, in the age of digitization, FQS is well improved by managing traceability through the assistance of I4.0 technologies. I4.0 technologies such as the IoT and blockchain significantly demand transparency, real-time control, and improved traceability in the supply chain (Hrouga et al., 2022). The I4.0 technologies offer enhanced FSC performance and ensure quality and safety (Dwivedi et al., 2022; Kayikci et al., 2022). Achieving zero hunger and food waste reduction is an important phase, including food security, since applying green practices in the supply chain help in improving food quality as well as effective waste management.

Insecurity, poor quality, and lack of food safety raise public health and wellbeing concerns, increase food wastage, and increase hunger. Food authenticity and labeling are becoming primary concerns for businesses, regulatory agencies, and consumers (Charlebois et al., 2016). Food makers and distributors are tampering with product ingredients to substitute or change them with inferior ones to establish a suitable price for the intended market or earn more profits. This phenomenon poses a severe risk to human health. For example, a Chinese milk scandal in 2008 discovered newborn milk formula poisoned with melamine, affecting 0.3 million infants (Demirbaş et al., 2008; Shanahan et al., 2009). Food safety may be improved by following appropriate processes, such as those described in the hazard analysis critical control point (HACCP) system while producing, transporting, processing, and storing food. However, according to Miarka et al. (2019), automating in a food processing factory is difficult. Recently, Carpigiani automated the machinery used in the ice cream and dairy industries, using blockchain technology for distributed HACCP storage and IoT for autonomous data collecting (mostly temperature, which is crucial for dairy products) (Biscotti et al., 2020). This study focused on the broad range of IoT and blockchain technology in the food sectors for security, safety, and quality control purposes that also revolutionize the green food supply chain due to the substantial applicability of these technologies in food processing plants. This study answers the question, *What are the GFSCM enablers of food security for reaching zero hunger by transforming the GFSC?*

The new cutting-edge technologies (IoT, AI, Big data and blockchain etc.,) help FSC to manage food quality and security by managing food waste, traceability, and real-time monitoring. Traceability within the FSC plays an integral part in food safety and quality. It establishes an end-to-end trust between farmers/manufacturers and consumers. Blockchain and IoT are the technologies used to improve the traceability in FSC that allow consumers and third parties real-time tracking of food products (Balamurugan et al., 2022; Casino et al., 2020; Rainero & Modarelli, 2021). Recent literature (e.g. Raheem et al., 2019; Chan et al., 2020; Xu et al., 2021 etc.,) reveals the positive role of technologies like; IoT, blockchain, big data analytics, etc., in GFSCM and FQS improvement through digitizing the supply chain. However, Chan et al. (2020) studied drivers of the food supply chain that enhance food security in a sustainable environment without focusing on cutting-edge technology, but they suggest from their analysis that implementing new technology will boost security. However, food industries are struggling to implement IoT and blockchain in their supply chain for quality, safety, and security enhancement. Hence, the analysis of enablers for food security helps the practical application of IoT and blockchain to transform the GFSCM. Therefore, we suppose to provide an answer to the two research questions that assist managers in implementing and transforming their green food supply chain, *what is the hierarchical structure and importance level of GFSCM enablers for improving food security, And what is the weightage and ranking of the GFSCM enablers, and what role does it play in food security and achieving zero hunger?* Few researchers, including Saha et al. (2022), have examined blockchain as a game-changing technology on the path to net zero in the sustainable food supply chain. However, they have not emphasized learning about and analyzing the critical enablers that digitally transform the GFSC to improve food quality, safety, and security and ultimately for zero hunger. Therefore, this study identifies the GFSCM enablers of food security improvement using IoT and blockchain to fill this knowledge gap. It analyzes their relationship to explore their role in achieving zero hunger by transforming the green food supply chain. This study focuses on SDG: zero hunger. Its main aim is to help literature and practitioners achieve zero hunger which is far behind the 2030 target (as per UN), by improving food security and quality (SDG2) and good health and wellbeing (SDG3). The main objectives of this study have been enlisted below.

1.1 Research objectives

RO1. To identify the modern GFSCM enablers for food security.

RO2. To investigate contextual interrelationship and hierarchy structure of GFSCM enablers and reveal their level of importance.

RO3. To compute the weightage and ranking of the GFSCM enablers and find their role in food security and zero hunger.

An integrated qualitative multicriteria decision-making (MCDM) methodology has been utilized to fulfill the proposed research objectives. Based on research objective to explore the contextual interrelationship, relationship hierarchy, and level of importance for each enabler, the interpretive structural modeling (ISM) approach has been utilized. Like similar research objectives, researchers utilized a decision-making trial and evaluation laboratory (DEMATEL) methodology, which failed to provide a relationship hierarchy and importance level of each enabler. However, DEMATEL has some advantages as it provides the intensity of the interrelationship among the factors.

The analytical network process (ANP) methodology has an advantage over the analytical hierarchy process (AHP) as it works on a broad network model instead of a hierarchy in AHP. Therefore, we utilize the (ANP) methodology that prioritize the enablers and determines the weight of each enabler. As this study has twelve enablers and has an interrelationship network structure and relationship hierarchy obtained from ISM, the ANP methodology provides the best solution in this context. Hence, the authors adopted an integrated ISM and ANP methodology to answer the proposed research questions. Based on research findings, we provided implications for theory development and managerial and SDG perspectives.

The structure of manuscript is as follows; in the second section of this study, previous research related to this study is discussed. The adopted research methodology is briefly discussed in section 3, while the application of the methodology is discussed in section 4. The findings obtained from the integrated research methodology have been discussed in section 5 with research implications. Finally, the research has been concluded in section 6 with future research recommendations.

2. Literature review

2.1. Green supply chain management (GSCM)

Srivastava (2007) defines GSCM as incorporating environmental thinking into supply chain management, including product development, green procurement and material selection, green production steps, distribution of the final product to the customer (green transportation), and product end-of-life management after its usable life. GSCM is the first step toward environmental sustainability (Adams et al., 2022). It has inspired numerous businesses and scholars to work on it to conserve the environment for future generations. Because numerous organizations have begun to recognize its significance, the literature on GSCM is expanding yearly. Green design, green buying, green production, green transportation, and reverse logistics are the primary activities engaged in GSCM (Solér et al., 2010). Green design is a strategy for designing products with improved biological quality by minimizing their negative influence on the environment throughout their life cycle (Silva et al., 2019). It entails considering the environment throughout the design process of a product. Green sourcing encompasses everything sourced from suppliers, subcontractors, service providers, and others and incorporates environmental standards that may be applied to all phases of the sourcing process. Green manufacturing tries to reduce environmental effects through improved consumption, such as minimizing harmful emissions and waste (reuse), and lower consumption through reduced use of energy and raw materials (Silva et al., 2019).Green packaging, transportation, procurement, and waste management practices are some of the green practices used in the food industry to achieve the desired goal (Zailani et al., 2012).

To reach at zero hunger food insecurity is the largest obstacle along with safety and bad quality of food which occur due to lack of traceability, poor management, food fraud and many more (Vogliano et al., 2021). As previously noted, food insecurity and poor quality produce a considerable quantity of food waste; therefore, security and quality control are critical. Some of the green practices that assist accomplish food security, quality, and safety are traceability, HACCP monitoring, green and sanitary packaging, and efficient transportation (Aung & Chang, 2014b). However, technology-assisted green activities improved food shelf life, quality, and security, and good traceability implementation led to lower greenhouse gas (GHG) emissions. Therefore first we discuss the food security and safety issues in the supply chain and how it help to the SDG attainment in the next section after that we will discuss how these issues are tackled in literatures through digital technologies.

2.2.Food security issues in GFSCM and SDGs

Food safety and quality are essential in life. Everyone deserves safe, secure, and good quality. The FSC plays a crucial role in providing consumers safe, secure, and high-quality food (Dora et al., 2021). Food fraud is the primary supply chain issue for food safety, insecurity, and quality (Onyeaka et al., 2022; Yang et al., 2022). Food fraud is defined as a set of behaviors carried out purposefully or inadvertently for monetary advantage. Food fraud, according to (Spink & Moyer, 2011, Page no. 158) "*the purposeful and intentional replacement, addition, manipulation, or manipulation of food, food components, or food packaging, or false or misleading assertions made about a product, for economic advantage*". According to preliminary estimates from the food insecurity experience scale, made accessible for around 150 countries in 2014 and 2015, sub-Saharan Africa has the highest rates of food insecurity, as conflicts plays the driver role for acute hunger (King et al., 2017; McKenzie & Williams, 2015). In that region, one-fourth of the adult population experienced severe food insecurity, and more than half experienced moderate to severe levels. The second-highest frequency was found in Southern Asia, where 12% of adults and 25% of adults overall reported severe food insecurity (Krishnamurthy et al., 2014).

Food security cannot exist without food safety, a commonly accepted fact. Food safety is a global problem. Indeed, the SDGs strongly relate to food safety (Vogliano et al., 2021). Goal 2 (zero hunger) aims to ensure food security and find long-term solutions to abolish all types of hunger by 2030 (Montagnini & Metzel, 2017; Vogliano et al., 2021). The goal is to guarantee that everyone can access enough wholesome food to maintain a healthy lifestyle, supporting SDG3, good health and wellbeing. Better food access and extensive promotion of sustainable agriculture are necessary to meet this goal. This involves fostering fair access to land, technology and markets, sustainable food production systems, and resilient agricultural techniques to increase the productivity and incomes of small-scale farmers(Montagnini & Metzel, 2017; Movilla-Pateiro et al., 2021). More money must be invested through international collaboration to boost agricultural productivity in emerging nations. Food availability is no longer a factor in hunger endurance (Movilla-Pateiro et al., 2021). Food insecurity caused by political upheaval and natural or human-made tragedies resulted in considerable portions of the population in many nations not receiving appropriate food, resulting in a failure to achieve the SDG zero hunger (Shi et al., 2019). Several technologies such as big data analytics, blockchain, IoT, and Artificial Intelligence (AI), to enhance food security, safety and quality control (Saurabh & Dey, 2021). To handle the food security, safety, and quality issues, IoT and blockchain technology has an important role in providing authenticity and transparency which will discussed in the next section shows how previous articles used it.

2.3.IoT and blockchain technology adoption in the food supply chain

Several food safety issues have shaken consumer confidence during the past ten years. However, several cutting-edge technologies, such as the IoT and big data, have been employed to address issues with food safety. But many are helpless in the face of data manipulation difficulties, which creates significant trust issues between upstream and downstream businesses. Blockchain can enhance the reliability of products and the connections between chain members since it is a shared, unchangeable database (Saurabh & Day, 2021). In addition, customers will be able to learn about and participate in the agri-food circulation footprint in the meantime. Meanwhile, it can assist in reducing "unsalable risk" in the agri-food industry. If utilized with Big Data technology, stakeholders can achieve more significant results (Liu et al., 2020). The potential of Blockchain to enhance supply chain management, in particular, has attracted much interest. For example, it demonstrates how the Ethereum Blockchain may be used in the soybean supply chain to eliminate the need for a central authority, while still allowing for tracing, tracking, and commercial transactions (Salah et al., 2019). With the increasing rise of the IoT, several academics are considering using relevant technologies for GFSCM traceability systems. According to Folinas et al. (2006), the efficiency of a traceability system is dependent on the capacity to track and trace each product and logistics unit, allowing for continuous monitoring throughout primary manufacturing to ultimate disposal by the user

Recent research emphasized the availability of analytical frameworks for IoT and Blockchain applications in the food and agriculture industries and the absence of analytical and empirical studies (Ben-Daya et al., 2019). In the I4.0 age, tracking the transportation of food along the supply chain entails identifying entities and locations. Examples include barcodes, wireless sensor networks (WSN), alphanumeric codes, radio frequency identification (RFID), and other data-capture technologies. According to Aung and Chang (2014a), RFID is the most advanced technology for food traceability, and many businesses are already utilizing it. Using a combination of alphanumeric identifiers and

RFID, Regattieri et al. (2007) created a technique for tracing cheese products that enable customers to follow the product they have purchased. Cattle may be tracked using an RFID-based system from farm to butcher (Feng et al., 2013; Shanahan et al., 2009). Thakur and Donnelly (2010) provided a standardized architecture that uses a relational database management system and XML for the soybean supply chain traceability.

I4.0 is a new digital revolution incorporating information technology (IT) to enable real-time tracking of industrial equipment and its interaction with other company services. Because of its pedigree in secsurity and traceability, blockchain technology is gaining traction in the IoT business (Reyna et al., 2018; Mishra et al., 2022). I4.0 technologies provide an additional competitive advantage to the FSC regarding food quality, safety, and security (Lezoche et al., 2020). Food organizations use IoT and blockchain technologies to tackle traceability (Balamurugan et al., 2022; Rainero & Modarelli, 2021). Traceability is one of the important issues in the FSC, affecting the food quality and improving safety and SC performance (Alabi & Ngwenyama, 2022; Rana et al., 2021). Blockchain, in particular, has lately been advocated in many industrial use cases, owing to its capacity to register events in a distributed and secure way without the need for a trusted centralized authority (Saurabh & Dey, 2021). For example, blockchain has been used in real estate to assure data consistency in management processes and in industrial contexts to dynamically slice and assign network resources (H. Xu et al., 2020). It provides a solution to the inaccessible traceability records and fraudulent operations by employing RFID for livestock identification (Shanahan et al., 2009). In automating the tracking of food products, the Quick Response (QR) code and RFID have been introduced in the FSC. For example, in the case of chicken meat, RFID is used across the supply chain, from the farm to the slaughterhouse and processing plant, and finally to the store (Feng et al., 2013). RFID readers collect and register traceability data, which is then forwarded to a central database. Customers may access data from a centralized database using devices at certain places to get the essential details about chicken meat (Feng et al., 2013). IoT and blockchain technology may be used to reduce food fraud, manage precise inventory, and enhance HACCP even if the IoT and blockchain-driven traceable system already provides consumer satisfaction (Soon, 2022; Xu et al., 2022). Blockchain is a promising technology that may be used to enhance food safety, quality, and performance, claims a 2022 research by Xu et al (2022). By enabling the rapid interchange of data about the source, lot number, and date of manufacture as well as the openness and transparency of the production environment and food safety certification, the food sector can improve food safety and boost consumer trust (Galvez et al.,2018). From the prior discussion, it is evident that the Internet of Things and blockchain has the potential to manage food security, safety, and quality issues, but in fact, they are not being widely adopted. Researchers such as (Rana et al. 2021), Khan et al. (2020), Saurabh and Day. (2021) suggests requirement of digital transformation for supporting broader technology adoption in GFSCM to control the food quality, reduce food insecurity to reduce hunger. Some of the research gaps obtained has been discussed in the next section.

2.4.Research Gaps

In the recent Covid-19 pandemic disruption, demand for safe, secure, and good-quality food is increasing (Ji & Ko, 2021). Food security is the ultimate requirement for consumers, and FSC managers must deliver high-quality, safer, and more secure (Ji & Ko, 2021; Qian et al., 2022; Sufiyan et al., 2019a). Food security, safety, and quality are the primary issue the United Nations raises as it is highly responsible for achieving zero hunger and good health and well-being (Blesh et al., 2019). The zero hunger goal is far behind and raises concern over its achievement by 2030 because of food fraud and insecurity (Thapa Karki et al., 2021). Also, a large amount of food waste generation and lack of waste management raises concerns. Therefore, it is necessary to find a way to implement green practices in the supply chain, which also satisfies food security, quality, and safety concerns (Astill et al., 2019). In the new era of digitalization, I4.0 technologies like IoT and blockchain have been utilized to improve the FSC traceability, transparency, HACCP control, avoid food fraud, etc. (Arora et al., 2022; Balamurugan et al., 2022; Kayikci et al., 2022). Food insecurity and bad food quality lead to food waste and public health damage (Krishnan et al., 2020). To brace the food security/safety and quality, digital transformation of the green supply chain is required, and IoT and blockchain can do so (Xu et al., 2021). Several researchers (Balamurugan et al., 2022; Barbosa, 2021; Qian et al., 2022) highlight the importance of IoT and blockchain technology on food security improvement, whereas no research is available to explore enablers that transform green food supply chain toward food security. Modern GFSCM enablers for food security must explore green practices in the FSC. To date, no research is available that analyzes the GFSCM enablers of food security in the modern era for achieving zero hunger SDG2. An urgent study is required to tackle the food safety and quality issue in supply chain that help literature and managers to transform digitally to the green food supply chain and which provides this literature. Herein, this study identifies GFSCM enablers of food security by applying IoT and blockchain to achieve zero hunger which is shown in Table 1.

Insert Table 1

3. Methodology

In the research procedure, authors adopted a two-step ISM-ANP methodology to develop the contextual interrelationship among the GFSCM enablers of food security using IoT and blockchain. In the first step of the study, they performed an exhaustive literature review and discussion with experts for selecting I4.0-based GFSCM enablers. After the exhaustive literature review and discussion with experts, 12 FSC performance enablers have been identified in Table 1. From the literature, 16 enablers have been discussed with experts (please see table 2) out of the 16 enablers. They suggest 12 enablers. After selecting enablers, they interviewed the experts to get their opinion on the relationship among the pair of enablers and perform the ISM approach. In second research step, they utilized the ANP methodology to compute the weight and ranking of enablers. The utilized ISM-ANP approach has been briefly taken from Kumar et al. (2021), who utilized ISM-ANP to analyze I4.0 and circular economy barriers in the FSC.

3.1.Identification of technology-assisted GFSCM enablers for food security

Food quality and safety are the most critical enablers of food security in GFSCM towards sustainable development with I4.0 technologies. Other GFSCM enablers like HACCP, GHG emission, waste reduction, green and hygienic packaging, product shelf life, and many more are helpful during sustainable development. The enablers mentioned above are mainly utilized to improve the FSC performance for improving food security along with the goal of a green supply chain with minimum loss of environment. Inventory management is also one of the essential enablers along with logistics efficiency as the whole product supply system is based on it. Other GFSCM enablers for food security to sustainable development are; food traceability, shelf-life optimization, and green and hygienic packaging. IoT and blockchain are the most utilized technology, along with RFID for traceability improvement of the system that ensures no food fraud and higher safety. With the IoT, HACCP analysis is performed to improve food safety and quality. The identified GFSCM performance enablers for food safety and quality improvement have been shown in Table 1.

3.2. ISM

ISM is the contextual interrelationship modeling technique that is performed to model several factors such as enablers (Kamble et al., 2020; Kumar et al., 2022; Yadav et al., 2021), challenges (A. Kumar et al., 2020; Kumar et al., 2022a), critical success factor (Luthra et al., 2015). ISM provides a contextual interrelationship hierarchy along with the level of importance for each factor in their relationship. Structural equation modeling (SEM) is another analytical technique used for modeling the factors. However, SEM requires large data sets to test the significance level of the relationship, while ISM requires a small dataset. SEM techniques do not provide a hierarchical structure and their level of importance whereas it is used to test the prior developed model .

Step 1. Development of structural self-interaction matrix (SSIM)

In this step, authors develop a relationship-based lower triangular matrix. To develop a lower triangular matrix, they conduct an expert discussion program based on the judgment of experts. Filled the SSIM. The relationship between the pair of enablers is recorded using four alphabetical symbols (V, A, X, and O). All the four symbols have their significance such as V signifies enablers' i' leads to enablers 'j', A signifies enablers 'j' leads to enablers 'i', X signifies bot enablers 'I' and 'j' leads to each other while o signifies neither 'I' leads 'j' nor 'j' leads 'I' or has no relationship. Hence, by using these four symbols, SSIM is developed.

Step 2. Conversion of SSIM into initial reachability matrix (IRM).

After developing SSIM, authors convert the alphabetical symbols into binary digits (0,1). The conversion of alphabetical symbols into binary digits is followed by specified rules below.

If an entry in the (i,j) cell is 'V', then the entry at i,j is 1, and j,i is 0.

If an entry in the (i,j) cell is 'A', then the entry at i,j is 0, and j,i is 1.

If an entry in the (i,j) cell is 'X', then entry at i,j is 1, and j,i is 1.

If the entry in the (i,j) cell is 'O', then the entry at i,j is 0, and j,i is 0.

Step 3. Obtaining final reachability matrix (FRM)

For obtaining the FRM, the transitivity relationship has been checked, if any. All non-zero entry values of IRM have been manually checked to get the transitivity relationship. The transitivity relationship is performed in such a way that, if enablers 'P' is in relationship with enablers 'Q' and in the same instance enablers 'Q' has a relationship with 'R' then enabler 'P' must have a relationship with 'R', if the entry value of P to R is o, it must be replaced with 1* signifies partial relationship.

Step 4. Level partitioning and formation of hierarchical structure.

To obtain hierarchical structure and level of importance, partitioning has been performed on the FRM. The antecedent set has been obtained in the level partitioning reachability set by matching the entry value column and row-wise, respectively. The intersection set has been obtained by obtaining the intersection entry value of the antecedent and reachability set. Enabler whose reachability set entry value is same as intersection set is selected as the first level. Once enablers are selected, enablers are removed for the next iteration and performed the same procedure until the final enabler is selected. Hierarchical structure has been developed based on the level partitioning level. The enabler selected as the first level is placed at the top of the hierarchy, and the last level enabler is placed at the bottom of the hierarchy while same-level enablers are placed at the same level.

3.3.MICMAC analysis

Driving power and dependence power has been obtained by summing the entry value of the enabler column and row-wise, respectively. MICMAC analysis has been performed by plotting a graph between driving and dependence power. MICMAC plot is used to cluster the enablers into four categories, namely, autonomous (1^{st} Q), dependent (2^{nd} Q), linkage (3^{rd} Q), and independent (4^{th} Q).

3.4. Analytical network process: ANP

The ANP is the extended version of Analytic hierarchy process (AHP), which is utilized to analyze factors, sub-factors, goals, and alternatives weight through a single matrix called supermatrix. Compared to the AHP, the ANP approach has the advantage of prioritizing groups of items while considering both uni and bi-directional, dependent, and independent (Chen et al., 2019). The AHP approach is best used for linear relationships and cannot use to model network structure. Other than AHP, DEMATEL has already been used to create the causal relationship based on the established weight of the items and to identify the priority of the items when combined with ANP or AHP (Li et al., 2020). ANP has been applied with ISM to recheck the relationship among the factors, which helps to achieve zero or minimum error. ANP method has been applied in the following steps (Kumar et al., 2021).

3.4.1. Formation of the network model and initial supermatrix.

The relationship obtained from the FRM has been utilized to prepare the network model. Network model provides a relationship among the factors. Based on the network model initial supermatrix. 'W_x' has been generated by providing the weight of each pair of factors. The weight of each factor pair is obtained through AHP or from the panel of experts. This study obtains the weight of each pair of factors from the discussion with a panel of experts. The initial supermatrix has been prepared using Equation 1. The demographic profile of the panel of 17 experts is shown in Table 2.

$$W_x = \begin{matrix} G \\ c1 \\ c2 \\ \vdots \\ c_n \end{matrix} \overset{\begin{matrix} G & c1 & c2 & \cdots & c_n \end{matrix}}{\begin{bmatrix} .. & .. & .. & .. & .. \\ w_1^c & w_{11}^1 & w_{12}^2 & \ddots & w_{13}^3 \\ w_2^c & w_{21}^1 & w_{22}^2 & \cdots & w_{23}^3 \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ w_n^c & w_{n1}^1 & w_{n2}^2 & \cdots & w_{n3}^3 \end{bmatrix}} \quad \text{......................... Equation (1)}$$

Where; G denotes the goal of the problem, c signifies criteria, w_{21}^1 signifies the weight of the second criteria based on the first criteria.

3.4.2. Obtaining weighted supermatrix

To obtain weighted supermatrix W_n each entry of the initial supermatrix has been divided by the sum of the weight of the corresponding column d_j. The weighted supermatrix is also called normalized supermatrix obtained from Equation 2.

$$W_n = \begin{matrix} G \\ c1 \\ c2 \\ \vdots \\ c_n \end{matrix} \overset{\begin{matrix} G & c1 & c2 & \cdots & c_n \end{matrix}}{\begin{bmatrix} .. & .. & .. & .. & .. \\ \frac{w_1^c}{d_c} & \frac{w_{11}^1}{d_1} & \frac{w_{12}^2}{d_2} & \ddots & \frac{w_{1n}^n}{d_n} \\ w_2^c & \frac{w_{21}^1}{d_1} & \frac{w_{22}^2}{d_2} & \cdots & \frac{w_{2n}^n}{d_n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ w_n^c & \frac{w_{n1}^1}{d_1} & \frac{w_{n2}^2}{d_2} & \cdots & \frac{w_{nn}^n}{d_n} \end{bmatrix}} \quad \text{.... Equation (2)}$$

Where $d_j = \sum_{i=1}^{n} w_{ij}^j$

3.4.3. Formation of limit supermatrix and computing weightage and ranking of enablers

To obtain the weight of the criteria necessary to stabilize the supermatrix, authors compute the higher power of the weighted supermatrix until all the supermatrix rows are stabilized. The limit supermatrix 'L' obtained from Equation 3 provides the weight of the enablers used to obtain ranking.

$$L = \lim_{g \to \infty} (W^{\propto})^g \quad \text{........................... Equation (3)}$$

4. Case illustration

4.1.Case selection

The utilization of green practices in the FSC is the ultimate requirement in the current scenario for lowering food waste and delivering eco-packaged food to the consumer to achieve zero carbon emissions. Food security, food safety, and quality have the ultimate role in reducing food wastage and hunger. Hence, food security, food fraud, and food quality have all become major issues throughout the world. Customers have occasionally voiced worries about the safety of food goods because they are intended to be consumed and directly influence health. Significantly shifting customer attitudes and stronger food laws and regulations have been significant factors that have compelled enterprises to assure the quality, safety, sustainability, and effectiveness of food goods and related services. Quality may be maintained by attending to the individual demands of food items. Certain fresh foods, for example, require refrigeration throughout travel and storage to manage parameters such as temperature, humidity, and contact with air or other substances (Parashar et al., 2020). With these issues, authors select food security as the primary focus to incorporate green initiatives in the FSC to achieve zero hunger. Thus, they identify GFSCM enablers of food security in support of IoT and blockchain.

4.2.Data collection

India ranked 107th out of 121 countries on the list of those that have achieved zero hunger (2022 Global Hunger Index). Therefore, we chose to collected data from Indian experts as India has an more food fraud, which leads to high rates of food insecurity and causes health problems and even the loss of life for some people; recently, due to spurious liquor caused 70 deaths. We established several criteria for sending questionnaires to experts, such as having more than five years of experience in academics or industry and a minimum qualification of a bachelor's degree. Furthermore, the expert should have minimum 5 years of experience as well as aware about digital transformation. Academic experts must work at national-importance institutions, whereas industrial experts must work in industries that have been founded for at least ten years as of 2022. To conduct preliminary screening of enablers, we sent a questionnaire to 50 experts that included a list of 16 enablers as well as demographic information. 17 of the 50 experts answered, recommending 12 enablers for this project that have the potential to digitally transform the GFSCM and aid in hunger-reduction. From Table 2 demographic profile of experts, only one expert has a graduate degree as the the highest qualification, while 7 have post graduate and 9 have a doctoral degree as their highest qualification. We have nine experts from academics and eight from the industry. Table 2 shows the expert demographics. Nine of the 17 are academics, with the remaining eight coming from industry. Only seven of the 17 specialists have fewer than ten years of expertise, while ten have more than seven years. The 17 experts are brought together in a Microsoft TEM-based discussion panel to complete the ISM relationship matrix jointly. The same group of specialists responds once more to questions about the preliminary ANP supermatrix preparation.

Insert Table 2

5. Application of ISM-ANP and analysis of findings

5.1.Application of ISM

The earlier discussed research methodology in section 3 has been adopted to perform the ISM methodology. In the first step, authors develop the SSIM from the opinion provided by the experts. Seventeen experts with teaching experience of more than five years in FSC background have provided their opinion on the development of SSIM. The SSIM has been provided in Table 3.

Insert Table 3

The alphabetical symbol of SSIM has been converted into a binary digit to obtain the initial relationship matrix depicted in Table 3. In the formation of Table 4, authors use the conversion rule discussed in step 2 of the ISM methodology. After obtaining the IRM, they obtained FRM by applying a transitivity check. The FRM has been provided in table 5. The transitivity relationship is highlighted in yellow color. The transitivity relation of the enablers shows the partial relationship between the two.

Insert Table 4

Insert Table 5

After obtaining FRM, the driving and dependence power have been computed. The FRM is used for level partitioning. In this study, authors obtained seven critical levels. The level partitioning matrix is shown in Table 6. According to findings, food quality is selected at the first level, while blockchain and IoT are selected at the seventh level. The importance level obtained from the level partitioning is used to develop the interrelationship hierarchy shown in Figure 1.

Insert Figure -1

Insert Table 6

5.1.1. MICMAC analysis

MICMAC analysis uses the driving power and dependence power value computed from the FRM. MICMAC plot has been provided in Figure 2. In the MICMAC plot enablers are classifies into four group based on their driving and dependance power.

Insert Table 7

Insert Figure -2

5.2.Application of ISM- ANP

5.2.1. Formation of network structure and obtaining initial supermatrix

Based on the hierarchy digraph (Figure 2) and final reachability matrix (Table 5), an ANP network model has been constructed, shown in Figure 3. The ANP network diagram diagrammatically represents the relationship among the enablers. Based on the relationship obtained from the final reachability matrix, authors used it to construct the initial supermatrix. The initial supermatrix is prepared based on the response obtained from the panel of expert discussion. The demographic profile of the experts has been shown in Table. On the Microsoft Teams platform, a panel of experts has discussed and provided their opinion to construct the initial supermatrix shown in Table 8.

Insert Table 8

Insert Figure -3

5.2.2. Computation of limit supermatrix

The initial supermatrix has been normalized to obtain a weighted supermatrix using Equation 2 in Table 9. The normalized weighted supermatrix has been stabilized to get the weight of the enablers. The stabilization of the supermatrix has been done using equation 3 and given in Table 10.

Insert Table 9 and 10

5.2.3. Obtaining weightage and rank of the performance enablers

The limit supermatrix has been used to compute the weight of the enablers and their corresponding ranking in Figure 4. The weight of each enabler is provided in the network diagram in Figure 5.

Insert Figure -4 and 5

5.3. Analysis of research findings

5.3.1. Analysis of ISM-MICMAC findings

The ISM technique has been applied to obtain the contextual interrelationship among the enablers and to produce hierarchical digraph. From the level partitioning (Refer to Table 6) hierarchical structure has been prepared, shown in Figure 1. From the hierarchical structure, IoT and blockchain are placed at the bottom of the hierarchy, on the other hand Food quality is placed at the top of the hierarchy, and food safety is placed second. The enablers placed at the bottom level signify as driver of system and belongs to the independent group of the MICMAC analysis because they have high driving power and low dependence power. Result shows IoT and blockchain both have high driving power of 12 each, which signifies both drives the enablers placed above them. Four enablers GHG emission, HACCP, traceability and inventory management placed at second from the bottom of hierarchy. Food safety and quality are placed at the top of the hierarchy with very low driving but high dependence power; hence, they belong to the dependent group of the MICMAC analysis. Traceability is placed at the second from the bottom and has the 6th level in level partitioning. The enablers at the bottom of the hierarchy are the driver of the system, which drives the enablers placed above the bottom level.

From the MICMAC analysis, logistic efficiency is placed in the autonomous group, while IoT is placed in an independent group. Blockchain is placed at the boundary of the independent group and linkage group while at the bottom of the hierarchy, which signifies it should be independent. From the suggestion of experts and ISM findings authors consider blockchain as the independent enablers and drivers of the system. The enablers in the autonomous group have lower driving and dependence power; hence it should be neglected, whereas logistic efficiency impacts the system, so experts suggests to not remove from the system. Food quality, food safety, and optimal shelf life of food products are placed in the dependent group and at the top of the hierarchy, signifying the highly dependent factor. Dependent group enablers have lower driving power but higher dependence power (details in table 7). In the linkage group with stronger driving and dependency power, the five enablers traceability, GHG emission, waste reduction, HACCP, and inventory management are particularly sensitive and typically the core of the systems. Finally, ISM findings suggest eight enablers systems, five from the core enablers group and three are logistics efficiency, green and sanitary packaging, and optimal food shelf life. These eight enablers are seen as a system of enablers that might digitally revolutionize the GFSCM utilizing IoT and blockchain technologies, resulting in improved food quality, safety, and security and the achievement of zero hunger.

5.3.2. ANP findings

Findings of ISM-MICMAC does not provide the weightage and raking of the enablers especially for the linkage group of enablers. However, the application of ANP provide all the importance weighting of enablers, especially for the core enablers. From ANP findings IoT and blockchain are given the highest weights shown in Figures 4 and 5 whereas inventory management is given the lowest weight of 0.029 since it is assigned to the autonomous group in the MICMAC analysis. According to the ISM results, the ranks of IoT and blockchain are rather clear since they are the most influential, and ANP recommends the same, while MICMAC is also clear about inventory management because it comes from an independent group and has the lowest weight in ANP. The weights and ranks of the core group enablers are unclear, and in Figure 4, ANP clarifies the enabler weighting. Traceability is ranked third with 0.121 weights, followed by WSR, HACCP, and GHP with weightages of 0.101, 0.068, and 0.067, respectively.

6. Discussions and implications

This study utilized ISM methodology to investigate the IoT, blockchain integrated GFSCM enablers for food security has main motive is to enhance food security through disruptive I4.0 technology and discuss its role in the perspective of SDG, especially zero hunger. In this regard, twelve enablers of GFSCM have been identified and investigated their contextual interrelationship. In this section, authors discuss the findings obtained and provide implications of this study from theoretical and practical points of view.

6.1.Discussions

The authors framed three research questions earlier in this study. Here they discuss them based on the findings. *The first question is based on identifying GFSCM enablers of food security to achieve zero hunger with IoT and Blockchain technology for SDG achievement.* Herein the identified enablers are; Inventory management, GHG emission, hazard analysis critical control points., Food safety, green and hygienic packaging, blockchain technology, logistic efficiency, IoT, waste reduction, traceability, food quality, and optimum shelf life are obtained from past literature and discussion with academic and industrial experts.

We use the ISM presented in Figure 2 to answer our second research question: what is the hierarchy of interrelationships among the enablers of technology-assisted GFSCM, and how important are these relationships? To ensure that food commodities are properly stored and have a longer shelf life, the enablers hierarchy reveals that it is crucial to minimize waste and adopt traceability which is also align with the findings of Prashar et al. (2020) and Kumar et al. (2022a) According to Prashar et al. (2020), reducing food waste and implementing traceability work together to assist reach net zero, however Kumar et al. (2022a) claim that it switches to the circular economy will help promote sustainable consumption and production. However, according to Kumar et al. (2022), these enablers aid in making the supply chain circular while also transforming it to be more environmentally friendly, which is related to the circular economy. This is because green and sustainable supply chain management is the path to a circular supply chain, as a result of this study outcomes and outcome of the prior similar studies by Kaur. (2021) and Joshi & Sharma (2022) support that it is apparent that IoT and blockchain directly lead the food security. Traceability, HACCP methods, green and hygienic packaging material design, and optimal product shelf life all impact food quality and safety improvement, and all are influenced by IoT and blockchain (Saurabh & Dey, 2020). The bottom of the hierarchy suggests that IoT and blockchain are the essential drivers of the GFSCM system for security enhancement, which also aligns with Joshi & Sharma (2022). Food safety and quality are the most critical dependent facilitators of GFSCM as controlled by I-4.0 technologies. All enablers contribute to high quality, security, and safety in the food supply chain. The importance degree of four enablers of GHG emission, HACCP, Inventory management, and traceability, have the same function in enhancing food security according to the hierarchy. Blockchain plays a significant role in increasing food quality by strengthening the traceability system, also reported by (Feng et al., 2020; Parashar et al., 2020). Consumers may immediately follow the history of their food and delivery locations using the blockchain-based traceable system(Parashar et al., 2020). Blockchain-enabled traceability further simplifies inventory management by keeping inventory records up to date and providing real-time monitoring (Jiang et al., 2021).

To address our third question, i.e., *what is the weightage and ranking of the GFSCM enablers, and what role do IoT and blockchain play in food security,* ANP methodology has been employed. According to the findings of the ANP methodology in Figure 5, I4.0 technology, IoT is placed first, followed by Blockchain, with weights of 0.20 and 0.19, respectively. With the relevance of blockchain and IoT in food security enhancement, food traceability is rated third with a weightage of 0.121. Technology-driven waste reduction, HACCP, and green and hygienic packaging all significantly improve food security and are placed fourth, fifth, and sixth. The improved food quality, safety, and security lowered food wastage because more shelf life and better packaging increase food availability, which leads to zero hunger SDG 2 (Thapa Karki et al., 2021; Vogliano et al., 2021). Food security and safety also reduce the health consequences of food insecurity and improve well-being. Inventory management, food quality, logistical efficiency, and food safety are placed 12th, 11th, 10th, and 9th, respectively. Food safety and quality have been the most dependent factors on the GFSCM enhancers scheme. Shelf-life optimization, placed eighth in the system, is a significant enabler for improving food security using IoT and blockchain. The shelf-life optimization is primarily based on HACCP, green and hygienic packaging, and food traceability systems, all regulated by IoT and blockchain.

The authors answer the second part of the third research question, *what role do I4.0 technologies play in food security and achievement of zero hunger by transforming the green food supply chain?* To determine the function of IoT and blockchain to transform GFSCM for food security, ISM findings indicate it as a main drivers of the eight enablers systems. MICMAC study has placed IoT and blockchain at the top left corner and bottom of the hierarchy to categorize it as the independent enablers. Findings indicates IoT blockchain technology improves traceability, automated regulation, and HACCP management it also align with the findings of (Sunny et al., 2020). Blockchain and IoT aid in developing environmentally friendly and sanitary packaging materials and reducing GHG emissions (Bradu et al., 2022; Ren et al., 2022). The efficient and hygienic packaging design for food items reduces waste and GHG emissions, improving food quality (Wandosell et al., 2021). The Internet of Things also aids in product shelf-life optimization and sanitary packaging material design, with HACCP acting as a catalyst (Tucki et al., 2022). Food security necessitates a multifaceted strategy, ranging from social protection to providing healthy food, especially for children, to changing food systems to create a more equitable and sustainable society. IoT and blockchain technology provides technological push to the system that promises food security and safety, preserving the nutritional value of food and ensuring safety for eating (Raheem et al., 2019). Investments in social welfare and rural and urban regions are required so that the poor can access food and enhance their living standards.

6.2.Implications

This section of the study has provided several implications for literature (theory development), practitioners, and recommendation for managers for sustainable development based on the findings.

6.2.1. Theoretical implications

This study has various theoretical implications for addressing the existing gap in the present literature for technology-driven GFSCM enablers. This research has four significant consequences for literature that enhance recently formed theories.

(1) First and foremost, this research identifies and projects twelve food security-based technology-driven GFSCM enhancers in the current era. All enablers were derived from discussions with academics and industry specialists. These enablers are the most beneficial in improving food safety and quality using technologies. IoT and blockchain technologies have driven food security innovation, improving FSC performance.

(2) Authors made second addition to the literature by exploring the interrelationships among the identified enablers using the ISM methodology. The ISM technique also highlights the relevance of each enabler in food security, as well as their reliance and driving power. The dependence and driving power of enablers demonstrate how much they rely on others and how much driving power they have. Using MICMAC analysis, they classified the enablers into four categories: autonomous, dependent, linking, and independent. The outcomes of analysis show that IoT and Blockchain are the most independent enablers, and their placement at the bottom of the hierarchy indicates that these two are the drivers of the technology-driven GFSCM performance system.

(3) Third addition to the literature is investigating the role of I4.0 technologies, such as IoT and blockchain, in food security. Moreover, the study findings show that IoT and blockchain are the driving forces behind GFSCM enablers of food security. According to the MICMAC study, IoT and blockchain are at the bottom of the hierarchy and form a separate group of enablers. The findings also show that IoT and blockchain can help food traceability, green and sanitary packaging, HACCP, and shelf-life optimization. These enablers bring novel traceable systems, smart HACCP, efficient green and sanitary packaging design, and so on to immediately enhance food quality, increase food safety, reduce waste and food security.

(4) Fourth major addition to the literature is to rank the enablers based on their interrelationship. According to the findings, the I4.0 technologies IoT and Blockchain are the top two ranked GFSCM enablers. According to ISM results, inventory management and food quality are the lowest two ranked enablers since they are reliant enablers.

6.2.2. Managerial implications

This study has the following implications for the managers and practitioners of GFSCM for those who want to understand food security-based technology-driven GFSCM enablers and wish to improve GFSCM performance by focusing on food security. The main managerial implications are given below.

(1) The findings of this study help decision-makers and managers to identify the technology-driven food security-based GFSCM enablers. The study findings help managers understand the interrelationship among the enablers and how the enablers are interrelated.
(2) The study findings help managers understand each importance and hierarchical interrelationship of each enabler. The enablers driving and dependence power help managers to understand which enablers have driving potential and which one has dependence potential. MICMAC analysis findings help practitioners understand enablers in four clusters: autonomous, dependent, linkage, and independent. Based on the study findings industry should implement IoT and blockchain technology to improve food security by improving traceability, quality, safety, and utilization of HACCP technique.
(3) By applying ANP, GFSCM enablers are ranked. The ranking of enablers helps practitioners to get the interrelationship weight of each enabler in performance enhancement. Findings suggest IoT and blockchain are significant contributors and generate technological push to ensure food security and safety. IoT and blockchain highly influence food traceability and waste reduction practices. They are another major contributor to food security improvement.

6.2.3. Recommendations for the practitioner towards achieving SDGs

Based on findings, authors suggest practitioners implement I4.0 technologies such as blockchain and IoT in their FSC to enhance food security and achieve zero hunger. Utilizing blockchain and IoT technology in GFSCM improves food security. It directly impacts food traceability, green and hygienic packaging design, reducing GHG emissions, HACCP control, waste minimization, and food shelf-life optimization. The government has also made important initiatives to improve food security, focused welfare schemes across India, a National Food Mission, and the National Food Security Act. The Rashtriya Krishi Vikas Yojana, the Government Mission on Sustainable Farming, and several national programs on horticulture, agricultural technology, and livestock are paving the road for greater agricultural productivity in India. Robotic systems are getting smarter, able to see and respond to varied circumstances based on explicitly set parameters, thanks to the integration of a high-tech image processing system (Hasnan et al., 2018). Examples of this are identifying different food products on the same processing line and doing different jobs in the blink of an eye. Digital image processing in robots entails capturing a real-time picture by contactless methods, visual representation in the computer, automated analysis, and creation of control instructions based on the results or measure readings (Herakovic et al., 2011). This is very useful for food quality checks, including checking labeling correctness, color, and height or volume.

From results, IoT and blockchain are independent enablers that drive the whole GFSCM system for improving food security, safety, and quality. At the very first, the enablers at the fifth and sixth level, third and second from the bottom (HACCP, inventory management, traceability, GHG emissions, waste reduction, optimum food shelf life) are more closely related to IoT and blockchain, which makes the foundation in GFSCM for achieving desire security, ensuring good quality and safety. Blockchain-based traceability and waste reduction practices ensure food security and quality, while IoT-based GHG emission controlling, product shelf-life optimization, and HACCP controlling are highly responsible for food security. The technology-enabled GFSCM system help in achieving minimum or zero food wastage, high security, and safety, ensuring maximum availability of edible food to the consumer, and supporting zero hunger. The first indicators of SDG2 are to improve food security, and IoT blockchain-based system fulfills the first objective of zero hunger (SDG2). Technology-enabled effective waste management practices ensure another objective of SDG2 to ensure maximum edible food till end users use and achieve zero hunger. Blockchain and IoT-based enhanced food security not only help to achieve zero hunger it also helps to achieve good health and wellbeing (SDG3). Also, IoT and blockchain manufacturing systems need to fulfill industry innovation and infrastructure (SDG9).

Also, based on the finding of this study, authors suggest combining IoT and Blockchain to increase the capacity to detect food manufacturing errors in the supply chain. On the one hand, the IoT enables remote testing of pasteurized processing temperature readings, relieving operators of the error-prone burden of sampling temperatures. On the other hand, the Blockchain enables the safe storage of temperature data in a quasi-way, making it impossible for any player participating in the process to alter the data once it has been saved.

6.3. Limitations of research

This study has several limitations, such as; first, this study identifies GFSCM enablers with the main focus on enhancing food quality and food safety. Second, the authors incorporate only twelve enablers extracted from literature and experts' discussions and some directly from experts' opinions. Finally, the SSIM table was prepared from the decision with 17 experts (8 industrial and nine academic experts). Based on the literature, a panel of 17 experts is sufficient for the SSIM preparation, varying from 7-20. For ANP methodologies, they prepare an initial supermatrix with an expert panel of 15 experts (13 same from ISM and two different academic experts). Hence, the inclusion and exclusion of expert's opinion findings may vary but not affect the results.

7. Conclusion and future research direction

This study utilized integrated MCDM tools ISM and ANP to analyze the GFSCM enablers of food security. While identifying GFSCM enablers, this study mainly focuses on food security and the interaction between blockchain and IoT as an enabler for achieving zero hunger (SDG2). Hence, from this study, readers may understand the role of IoT and blockchain for transforming the GFSCM to enhance security and safety. Based on the opinion of experts and past literature, twelve GFSCM enablers focusing on food quality, safety, and security have been identified for the study. The judgment of 17 experts has been utilized to explore the contextual interrelationship among the enablers using the ISM methodology. The ranking and significant weightage of the enablers were computed using the ANP methodology.

Results from the ISM approach strongly indicate that IoT and blockchain technology, positioned at the bottom of the ISM hierarchy, drive the GFSCM enablers system. In contrast, food safety and quality are the most dependent enablers, respectively, positioned at the top of the hierarchy. In order to transform GFSC, the seven enablers system is the core enabler that will operate as a mediator between IoT, blockchain, and Food quality and safety. from ANP findings, IoT and blockchain are the top-ranked enablers, with traceability coming in third. According to the authors' results, businesses may increase traceability, HACCP and shelf-life optimization, and waste reduction by implementing IoT and blockchain. The enablers above, including IoT and blockchain, promote greater food security and FSC productivity, directly contributing to SDG zero hunger. By combining IoT and blockchain, the SDG2 goal of zero hunger may be reached in two ways: by improving food security and reducing food waste.

From this study, authors recommend some future research direction that is not limited to this. First, some more enablers and different sets of experts may utilize to explore the findings, which may or may not be different. In the future, the causal intensity of the enablers may be computed by applying another MCDM methodology, such as DEMATEL. The selection of enablers may vary from expert to expert. However, we utilized opinions from 17 experts, which is not less. To entirely avoid the biasness in enablers and results, structural equation modeling may be utilized in the future to verify the results; however, we assume no more variation is expected.

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TABLES

Table 1 technology assisted GFSCM enablers for food security

Enablers	Discerption	Source
Inventory management: INM	Inventory management is a critical GFSCM enabler; it helps to provide a smooth flow of food product and help to ensure product availability. Good inventory management ensures lower food wastage.	(Parashar et al., 2020; Tayal et al., 2021)
GHG emission: GHG	GHG emission is the GFSCM enabler that helps to build environmental performance by working on the reduction of GHG. Waste reduction and management practices help reduce GHG emissions in GFSCM, which may reduce food insecurity.	(Barbosa, 2021; M. Kumar et al., 2021; Parashar et al., 2020; Rivera Huerta et al., 2016)
Hazad Analysis Critical Control Point: HACCP.	It is a food safety standard system designed by the food industry that analyses each stage in the food production process, identifies particular hazards, and applies effective control measures and monitoring methods. With HACCP, food quality and safety will improve, helping achieve SDG 2 and security.	(Y. Xu et al., 2022)(Miarka et al., 2019)
Food safety: FS	Food safety is a significant concern due to increased food fraud and lack of application of standardization. Food safety leads to good consumer health and wellbeing and improves customer satisfaction. In GFSCM, food safety has a major role in waste reduction.	(Khan et al., 2020; Parashar et al., 2020; Y. Xu et al., 2022)
Green and hygienic packaging: GHP	Green and hygienic packaging is the combination of two enablers, green and hygienic packaging, as suggested by the experts. Green and hygienic packaging are essential for food safety because they prevent food from fluctuating environments.	(Abuabara et al., 2019; Wandosell et al., 2021)
Blockchain technology: BCT	Blockchain technology is a newly emerging industry I4.0 technology utilized by industries to automate processes. Food processing industries utilized blockchain technology to enhance Traceability, quality, and security to give customers real-time tracking of their food products.	(Barbosa, 2021; Barge et al., 2020; Y. Xu et al., 2022)
Logistic efficiency: LOE	Food quality is highly dependent on available maximum shelf life to the consumer; therefore, logistic efficiency is an essential enabler of the food supply chain as it has much less shelf life than other non-food products.	(Kouhizadeh et al., 2021)
Internet of things: IoT	IoT is the core technology of I4.0 which is highly utilized in the industries for automatic monitoring of things. IoT in FSC has been utilized in various aspects such as; quality inspection,	(Balamurugan et al., 2022; H. Feng et al.,

	monitoring of safety standards, HACCP monitoring, etc., which improves the FSC performance.	2020a; Rahman et al., 2021)
Waste reduction: WSR	Approx. One-third of the total edible food gets wastage. Hence, food waste reduction is one of the significant challenges and instant requirement to save the environment and feed the population, directly improving the FSC performance.	(Machado et al., 2020; Molina-Besch, 2016; Muncke et al., 2020; Parashar et al., 2020)
Traceability: TRY	Food traceability is essential to track food products, including process history, locations, manufacturer identity, quality certification, etc. Traceability improves product transparency with stakeholders. With traceable systems, manufacturing organizations can track their inventory and manage their sales and demand.	(Miarka et al., 2019; Parashar et al., 2020; Rainero & Modarelli, 2021)
Food quality: FQL	Food quality is a vital GFSCM parameter, defined as the food available to end consumers with good texture, flavor, nutritional value, and higher expected shelf life. Worst food quality leads to health damage, environmental damage, and wastage of food products.	(Balamurugan et al., 2022; Nyamah et al., 2017; Sufiyan et al., 2019b)
Optimum shelf life: OSL	Food products, especially perishable food products, have a minimal shelf life which may be maximized by optimum temperature control and good packaging material. FSC performance and food quality are highly correlated with the shelf life of food commodities.	(Aung & Chang, 2014a; Kaipia et al., 2013; Xiao et al., 2017)

Table 2 Demographic profile

Expert	**Designation**	**Academic qualification**	**Field of Expertise**	**Experience**
E1	Assistant professor	Doctorate	Food Supply chain	10 years
E2*	Assistant professor	Doctorate	Digital supply chain	7 years
E3*	Associate professor	Doctorate	Food Supply chain	12 years
E4	Associate professor	Doctorate	Agri-food 4.0	12 years
E5	Assistant professor	Doctorate	Digital supply chain	7 years
E6	Professor	Doctorate	Smart manufacturing	18 years
E7	Professor	Doctorate	Digital supply chain	20 years
E8	Associate professor	Doctorate	Food quality	12 years
E9	Professor	Doctorate	Food quality	17 years
E10	Quality engineer	Post-Graduation	Total quality management	10 years
E11	Quality engineer	Post-Graduation	Total quality management	8 years
E12	Data operator	Graduation	Big data, IoT	8 years
E13	Procurement officer	Post-Graduation	Warehouse and material management	8 years
E14	Production manager	Post-Graduation	Food processing	10 years
E15	Production manager	Post-Graduation	Food processing	12 years

E16	Sales and marketing	Post-Graduation	HR and Business analytics	10 years
E17	Research and design	Post-Graduation	IoT, AI, and machine learning	8 years

Table 3 Structural self-interaction matrix for GFSCM enablers of food security

Enablers	INM	GHG	HCCP	FS	GHP	BCT	LOE	IOT	WSR	TRY	FQL	OSL
Inventory management: INM	1	A	A	V	A	A	O	A	X	A	V	A
GHG emission: GHG		1	X	V	X	A	V	A	V	X	V	V
Hazard Analysis Critical Control Point: HACCP.			1	O	V	O	V	A	X	X	V	O
Food safety: FS				1	O	A	A	O	A	A	O	O
Green and hygienic packaging: GHP					1	A	O	O	X	A	O	O
Blockchain: BCT						1	V	V	X	A	V	V
Logistic efficiency: LOE							1	A	A	O	O	A
IoT: IoT								1	V	V	O	V
waste reduction: WSR									1	A	O	O
Traceability: TRY										1	O	V
Food quality: FQL											1	O
Optimum shelf life: OSL												1

Table 4 Initial reachability matrix for GFSCM enablers of food security

	INM	GHG	HACCP	FS	GHP	BCT	LOE	IOT	WSR	TRY	FQL	OSL
INM	1	0	0	1	0	0	0	0	1	0	1	0
GHG	1	1	1	1	1	0	1	0	1	1	1	1
HACCP	1	1	1	0	1	0	1	0	1	1	1	0
FS	0	0	0	1	0	0	0	0	0	0	1	0
GHP	1	1	0	0	1	0	0	0	1	0	0	0
BCT	1	1	0	1	1	1	1	1	1	0	1	1
LOE	0	0	0	1	0	0	1	0	0	0	0	0
IOT	1	1	1	0	0	0	1	1	1	1	0	1
WSR	1	0	1	1	1	1	1	0	1	0	0	0
TRY	1	1	1	1	1	1	0	0	1	1	0	1
FQL	0	0	0	0	0	0	0	0	0	0	1	0
OSL	1	0	0	0	0	0	1	0	0	0	0	1

Table 5 Final reachability matrix GFSCM enablers of food security

	INM	GHG	HACCP	FS	GHP	BCT	LOE	IOT	WSR	TRY	FQL	OSL	DRV P
INM	1	0	1*	1	1*	1*	1*	0	1	0	1	0	8
GHG	1	1	1	1	1	0	1	0	1	1	1	1	10
HACCP	1	1	1	1*	1	0	1	0	1	1	1	1*	10
FS	0	0	0	1	0	0	0	0	0	0	1	0	2
GHP	1	1	1*	1*	1	1*	1*	0	1	1*	1*	1*	11
BCT	1	1	1*	1	1	1	1	1	1	1*	1	1	12
LOE	0	0	0	1	0	0	1	0	0	0	1*	0	3

IOT	1	1	1	1*	1*	1*	1	1	1	1	1*	1	12
WSR	1	1*	1	1	1	1	1	1*	1	1*	1*	0	11
TRY	1	1	1	1	1	1	1*	1*	1	1	1*	1	12
FQL	0	0	0	0	0	0	0	0	0	0	1	0	1
OSL	1	0	0	1*	0	0	1	0	0	0	0	1	4
dep p	9	7	8	11	8	6	10	4	8	7	11	7	

Table 6 Final level partitioning for GFSCM enablers of food security

Enablers	Reachability set	Antecedent set	Intersection set	level
Food quality	11	1,2,3,4,5,6,7,8,9,10,11	11	1ST
Food safety	4	1,2,3,4,5,6,7,8,9,10,12	4	2nd
Logistic efficiency	7,	1,2,3,5,6,7,8,9,10,12	7	3rd
Green and hygienic packaging	1,3,5,6,9	1,2,3,5,6,9,9,10,12	1,3,5,6,9,	4TH
waste reduction	2,3,5,6,8,9,10,	2,3,5,6,8,9,10	2,3,5,6,8,9,10	5TH
Optimum Food shelf life	12	2,3,5,6,8,10,12	12	
GHG emission	2,3,5,10,	2,3,5,6,8,10	2,3,5,10	6TH
HACCP	2,3,5,10,	2,3,5,6,8,10	2,3,5,10	
Inventory management	2,3,5,6,10,	2,3,5,6,8,10	2,3,5,6,10	
Traceability	2,3,5,6,8,10,	2,3,5,6,8,10	2,3,5,6,8,10	
Blockchain	6,8,	6,8,	6,8	7TH
IoT	6,8	6,8	6,8	

Table 7 Dependence power driving power and factor group

Factors	DRV. P	DEP. P	level	Factor group
INM	8	9	4th	Linkage
GHG	10	7	6th	Linkage
HACCP	10	8	6th	Linkage
FS	2	11	2nd	Dependent
GHP	11	8	6th	Linkage
BCT	12	6	7th	Independent
LOE	3	1	3rd	Autonomous
IOT	12	4	7th	Independent
WSR	11	8	5th	Linkage
TRY	12	7	6th	Linkage
FQL	1	11	1st	Dependent
OSL	4	7	5th	Dependent

Table 8 Initial super matrix

	Goal	INM	GHG	HACCP	FS	GHP	BCT	LOE	IOT	WSR	TRY	FQL	OSL
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0
INM	0.05	0	0	0.08	0.09	0.02	0.06	0	0	0.1	0	0.02	0
GHG	0.12	0.09	0	0.16	0.06	0.04	0	0.1	0	0.04	0.05	0.09	0.3
HACCP	0.09	0.13	0.1	0	0.1	0.31	0	0.06	0	0.21	0.08	0.15	0.16
FS	0.15	0	0.1	0	0	0.04	0.06	0	0	0.09	0.04	0.18	0
GHP	0.11	0.14	0.14	0.09	0.1	0	0.1	0.04	0	0.16	0.06	0.05	0.14
BCT	0.16	0.14	0.21	0.18	0.25	0.12	0	0.1	0.4	0.21	0.42	0.18	0.16
LOE	0.04	0	0	0	0.09	0.06	0	0	0.08	0	0.08	0.08	0
IOT	0.18	0.18	0.18	0.34	0.18	0.16	0.41	0.18	0	0.24	0.33	0.18	0.18
WSR	0.16	0.15	0.18	0.16	0.1	0.18	0.1	0	0.2	0	0.04	0.04	0

TRY	0.15	0.15	0.16	0.11	0.21	0.14	0.1	0.32	0.21	0.12	0	0.15	0.04
FQL	0.1	0	0.2	0	0	0	0		0	0.21	0	0	0.1
OSL	0.13	0.11	0	0	0.08	0	0.14	0.1	0.11	0	0	0.1	0.05

Table 9 Weighted super matrix

	Goal	INM	GHG	HACCP	FS	GHP	BCT	LOE	IOT	WSR	TRY	FQL	OSL
Goal	0	0	0	0	0	0	0	0	0	0	0	0	0
INM	0.035	0.000	0.000	0.071	0.071	0.019	0.062	0.000	0.000	0.072	0.000	0.016	0.000
GHG	0.083	0.083	0.000	0.143	0.048	0.037	0.000	0.111	0.000	0.029	0.045	0.074	0.265
HACCP	0.063	0.119	0.079	0.000	0.079	0.290	0.000	0.067	0.000	0.152	0.073	0.123	0.142
FS	0.104	0.000	0.079	0.000	0.000	0.037	0.062	0.000	0.000	0.065	0.036	0.148	0.000
GHP	0.076	0.128	0.110	0.080	0.079	0.000	0.103	0.044	0.000	0.116	0.055	0.041	0.124
BCT	0.111	0.128	0.165	0.161	0.198	0.112	0.000	0.111	0.400	0.152	0.382	0.148	0.142
LOE	0.028	0.000	0.000	0.000	0.071	0.056	0.000	0.000	0.080	0.000	0.073	0.066	0.000
IOT	0.125	0.165	0.142	0.304	0.143	0.150	0.423	0.200	0.000	0.174	0.300	0.148	0.159
WSR	0.111	0.138	0.142	0.143	0.079	0.168	0.103	0.000	0.200	0.000	0.036	0.033	0.000
TRY	0.104	0.138	0.126	0.098	0.167	0.131	0.103	0.356	0.210	0.087	0.000	0.123	0.035
FQL	0.069	0.000	0.157	0.000	0.000	0.000	0.000	0.000	0.000	0.152	0.000	0.000	0.088
OSL	0.090	0.101	0.000	0.000	0.063	0.000	0.144	0.111	0.110	0.000	0.000	0.082	0.044

Table 10 Limit super matrix

	Goal	INM	GHG	HACCP	FS	GHP	BCT	LOE	IOT	WSR	TRY	FQL	OSL
Goal	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
INM	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
GHG	0.047	0.048	0.048	0.048	0.047	0.048	0.048	0.048	0.048	0.047	0.048	0.048	0.047
HACCP	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068	0.068
FS	0.034	0.034	0.034	0.034	0.033	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.034
GHP	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066	0.066
BCT	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.197	0.198	0.197
LOE	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033	0.033
IOT	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.205	0.206	0.205
WSR	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101	0.101
TRY	0.121	0.121	0.121	0.121	0.120	0.121	0.121	0.121	0.121	0.121	0.121	0.121	0.121
FQL	0.028	0.029	0.029	0.029	0.028	0.029	0.028	0.029	0.029	0.028	0.029	0.029	0.028
OSL	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065

Figures

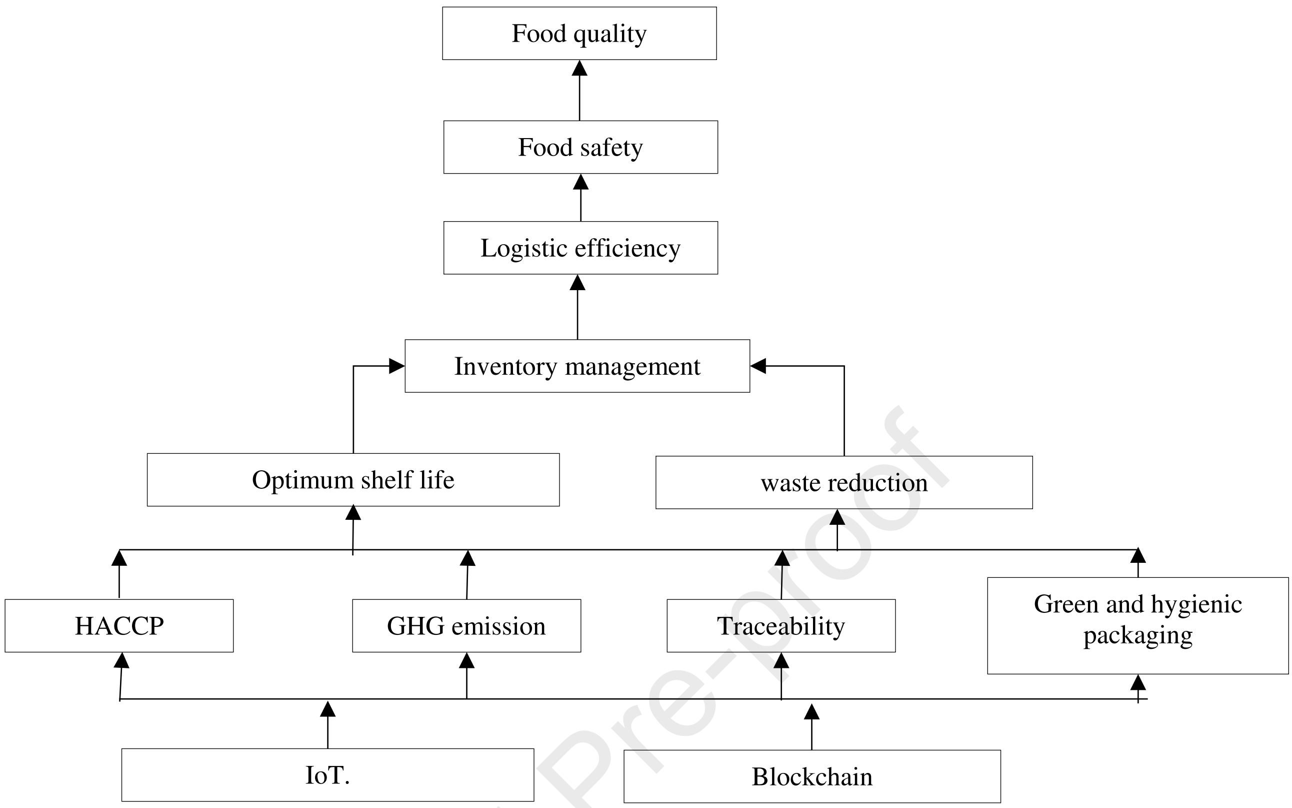

Figure 1 Hierarchy digraph for GFSCM enablers of food security

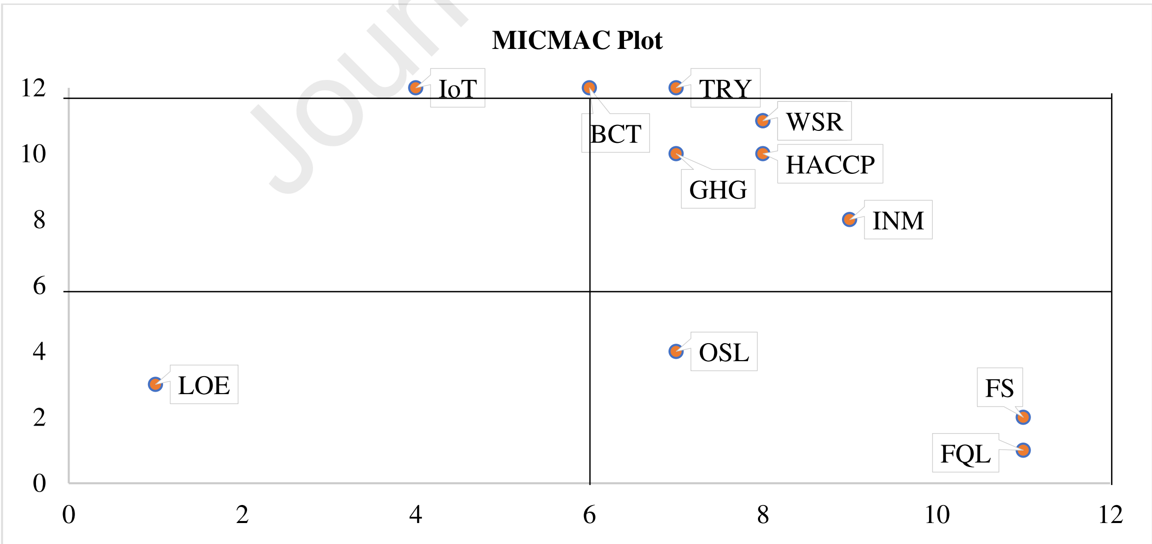

Figure 2 MICMAC plot for GFSCM enablers of food security

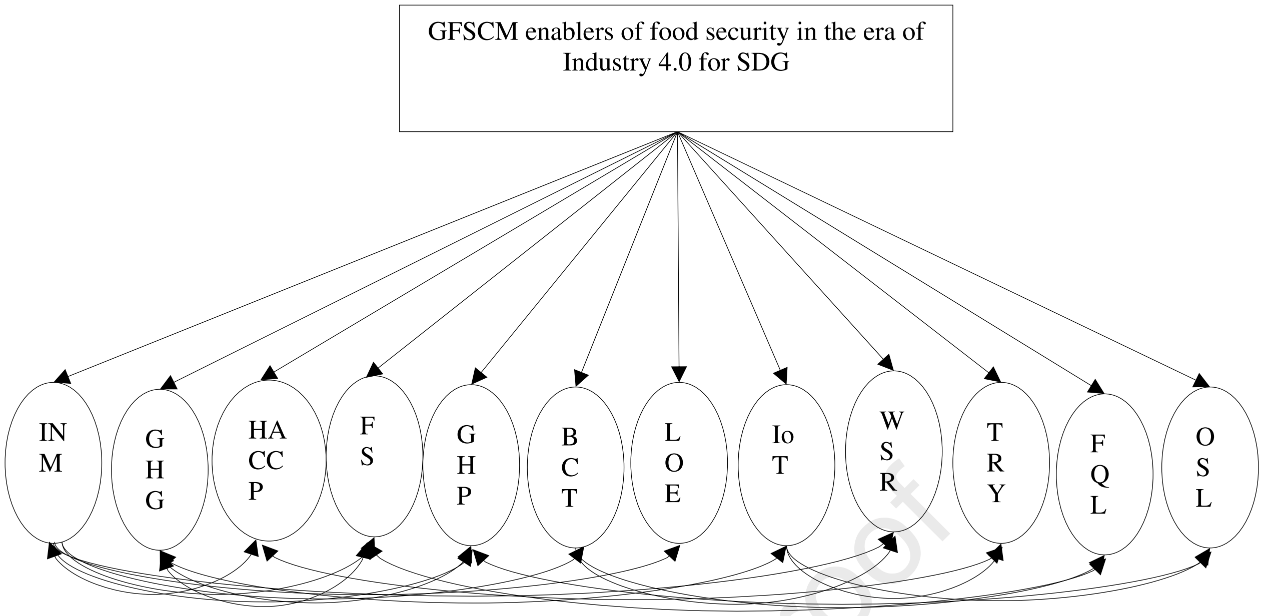

Figure 3 ANP network diagram

Figure 4 Weight and rank of the GFSCM enablers

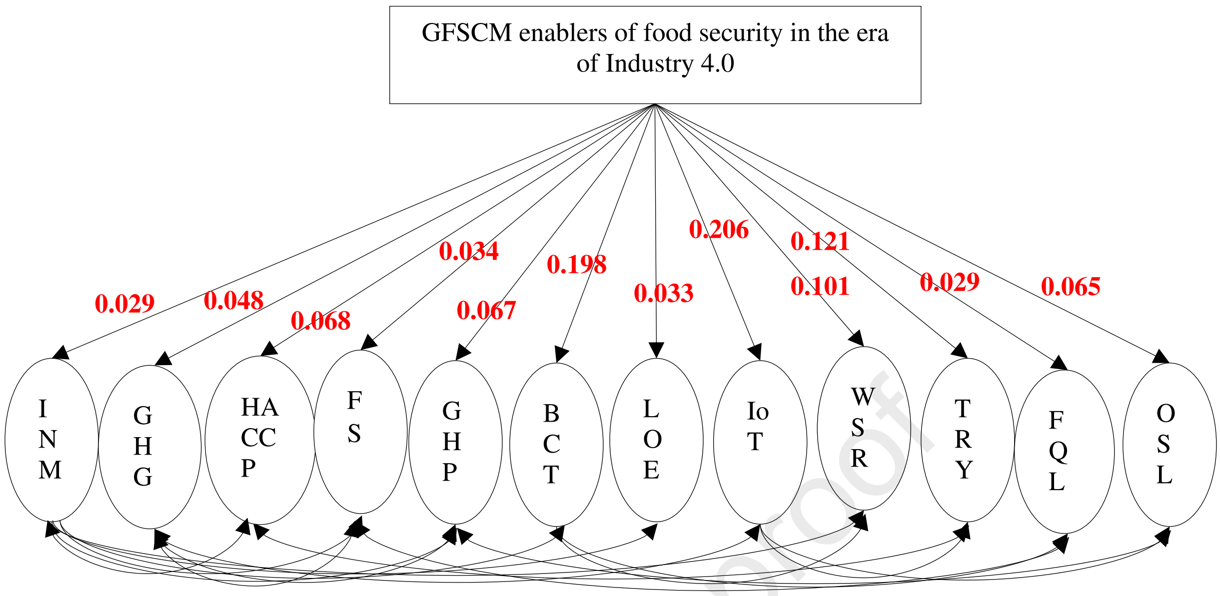

Figure 5 IoT blockchain-driven GFSCM enablers of food security

Highlights

1. digital technologies in GFSCM help improve food security
2. this study identifies modern enablers of GFSCM for food security
3. twelve GFSCM enablers of food security from literature and expert discussion
4. A two-step integrated ISM and ANP methodology has been utilized.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Enablers to achieve zero hunger through IoT and blockchain technology and transform the green food supply chain systems

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