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TOWARDS SUSTAINABLE DEVELOPMENT, EXPLORING LEAN, GREEN, CIRCULAR, AND SUSTAINABLE (LGCS) PRACTICES FOR MITIGATING FRUIT & VEGETABLE LOSS AND WASTAGE

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Abstract:- For sustainable development in the current global environment, managing losses and wastage in the fruit and vegetable supply chain is necessary. This article explores the interaction of several practices from lean, green, circular, sustainable, and technological practices on food supply chains using total interpretive structural modelling (TISM). This study investigates their contextual relationships to assess their influence on waste reduction and sustainable development. Green practices place an emphasis on environmental responsibility, while lean practices emphasize eliminating non-value-added processes. To examine their complexities, this manuscript reviews the literature. It examines sustainable social practices and the reuse of circular resources, highlighting the value of both the individual and the group. It also looked at its technology that enhances real-time monitoring, data analytics, and process optimization. The structural relationships, dependencies, and interactions between these practices are explored in this study using the TISM methodology. It talks about the causes of these behaviour as well as the barriers to their adoption. By exposing the intricate web of influences, this manuscript aims to assist practitioners, policymakers, and stakeholders in optimizing fruit and vegetable supply chains for sustainability. This article offers a thorough framework for controlling losses and wastage in the supply chain for fruits and vegetables. By analyzing the relationship between lean, green, circular, sustainable, and technological practices, this study adds to the body of knowledge on supply chain sustainability. It offers practical knowledge for a resilient and sustainable food system.

Keyword:- Sustainability , Supply Chain Management, Sustainable Development Goals, Lean, Green, Food loss, TISM.

1. Introduction

Within the framework of global sustainability, the effective management of waste and losses in the supply chains pertaining to fruits and vegetables has emerged as a matter of paramount significance (Yontar & Ersöz, 2021). Considering the substantial adverse impacts of these activities on the environment, economy, and society at large, it is crucial to formulate comprehensive strategies that adhere to the principles of sustainability (Shashi et al., 2020). The supply chains of fruits and vegetables (F&V) play a vital role in safeguarding global food security, promoting nutrition, and supporting the livelihoods of a significant number of individuals globally (Raut et al., 2018). However, they encounter substantial obstacles, such as prevalent inefficiency and wastage, degradation of the environment, and disparities in social equity. According to the Food and Agriculture Organization (FAO), a substantial amount of global food production, estimated at around 14%, is lost during the transition from harvest to retail. This loss is primarily attributed to fruits and vegetables (F&V). Furthermore, the waste and loss of fruits and vegetables (F&V) have been found to be a significant factor in the escalation of greenhouse gas emissions, the decline of biodiversity, the scarcity of freshwater resources, and alterations in land utilization (Negi & Anand, 2017). This article highlights the importance of enhancing the efficiency and long-term viability of fruit and vegetable supply networks. This article aims to examine the complex interconnections between lean, green, circular, and sustainable approaches to effectively address the management of fruit and vegetable waste and loss within supply chains. Objective of this manuscript is to offer a comprehensive strategy that not only tackles waste reduction but also contributes to broader sustainable development objectives by analysing these interrelated interactions.

The complexity of contemporary supply chains and rising consumer demand for environmentally friendly practices have increased the need for efficient waste and loss management techniques (Baralla et al., 2021; Mor et al., 2015). Integrating lean practices results in increased efficiency and decreased waste by emphasizing the elimination of non-value-added processes (Zekhnini et al., 2022). Green practices, on the other hand, emphasize environmental responsibility and encourage businesses to minimize their ecological footprint through efficient resource use and pollution control (Ye et al., 2023). The circular economy idea emphasizes promoting resource reuse and closing the material loop, closely aligning with sustainability principles (De Angelis et al., 2018). A comprehensive strategy that acknowledges the interconnections of various practices capable of improving the performance of fruit and vegetable (F&V) supply chains could be used to address this challenge. Lean, green, circular, and sustainable (LGCS) principles are all incorporated into these procedures.

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Continuous improvement, customer focus, and flow management are all components of lean practices, which place a priority on waste elimination and value optimization (De Steur et al., 2016; Shah & Naghi Ganji, 2017). Green practices use energy efficiency, waste reduction, and pollution control to reduce the environmental impact of supply chain operations. Utilizing tactics like product design, reverse logistics, and industrial symbiosis, circular practices promote the reuse, recycling, and recovery of materials and resources throughout supply chains. The social facets of supply chain management are covered by sustainable practices, which address issues like respect for human rights, compliance with labor laws, stakeholder engagement, and community development(León-Bravo et al., 2017). In order to improve the effectiveness, responsibility toward the environment, circularity, and overall sustainability of F&V supply chains, these LGCS practices can be integrated.

Despite the potential benefits LGCS practices could bring to fruit and vegetable (F&V) supply chains, little empirical research has been done to examine how these connections affect waste and loss management. Most studies focus on just one or a few aspects of LGCS practices, frequently ignoring their complex interactions and potential trade-offs. Additionally, these studies often take a single viewpoint, such as economic, environmental, or technical, while ignoring the many factors (such as social, institutional, and behavioral ones) that impact F&V supply chains. This knowledge gap necessitates a comprehensive strategy that embraces various viewpoints on sustainable development. By exploring the contextual relationships tying LGCS practices within F&V waste and loss management in supply chains, this manuscript aims to close this gap. This manuscript also aims to shed light on this topic by combining quantitative and qualitative data collection and analyzing methodologies in a mixed-research design. To determine the current situation and underlying factors influencing the adoption of LGCS practices, a survey of important F&V supply chain participants in India is conducted. In-depth case studies of F&V supply chain players in India are also conducted to examine the challenges and opportunities presented by adopting LGCS practices. Through this investigation, advances in sustainable waste and loss management are attempted by deepening the understanding of the dynamics of LGCS practices in F&V supply chains.

Research objectives

i. *To explore the LGCS practices for tackling fruit and vegetable losses and wastage*

ii. *To explore contextual interrelationships and discuss the impact of LGCS practices on F&V waste and loss management towards sustainable development*

To understand how these practices collectively contribute to the comprehensive management of wastage and losses in the fruit and vegetable domain, this manuscript delves into the complex web of interactions and interdependencies that bind them. The goal is to map the connections between these practices using the total Interpretive Structural Modeling (TISM) method, highlighting their interdependence and potential synergistic effects. This methodology also makes it easier to identify the practices that play a crucial part in directing the system as a whole and its transformational journey towards sustainability. The TISM methodology's power lies in its capacity to make complex interactions visible, illuminating how lean, green, circular, and sustainable practices can work together harmoniously to support waste and loss management. This comprehensive approach not only addresses current issues but also complies with more general aspirations for sustainable development, such as the Sustainable Development Goals (SDGs) of the United Nations. This research, which examines the interactions of these practices through the lens of TISM in the context of growing global sustainability imperatives, contributes to the academic discourse. Investigations carried out in this research about the connections between these practices in managing fruit and vegetable wastage and losses promises practical advice for practitioners, decision-makers, and other stakeholders committed to strengthening sustainability and optimizing supply chains. The main goal of this manuscript is to unravel the complex web of lean, green, circular, and sustainable practices in fruit and vegetable waste and loss management. Through the TISM framework, an attempt to unveil potential trajectories for realizing sustainable development, all while tackling the acute predicament of waste and loss within supply chain is endeavored.

2. Literature Review

2.1. Fruits and vegetables loss and waste management

Several factors, including deficiencies in infrastructure, limited technical and administrative expertise, inadequate coordination, ineffective communication between stages, and consumer attitudes, influence the management of food loss and waste (FLW), which is a critical element of the food supply chain (FSC) (Gardas et al., 2017; Halder & Pati, 2011). Various factors, including megatrends, natural limits, and managerial root causes, play a significant role in the occurrence of food loss and waste (FLW) (Fabi et al., 2021; Magalhães et al., 2021). It is observed that FLW is more prevalent in developing nations and tends to occur at later stages in the supply chain in developed countries.

Various authors have extended their analysis beyond mere identification of the origins and focal points of flexible work arrangements (FWAs) within flexible workspaces (FSCs) and have proactively categorised these factors. In their study, (Mena et al., 2011) classified the most significant factors into three overarching categories: megatrends, natural limitations, and managerial underlying causes. According to the classification proposed by (Canali et al., 2016), the factors contributing to food loss and waste (FLW) can be categorized into two main groups: inadequate supply and demand management and suboptimal quality and process control. In their study, (Willersinn et al., 2015) employed this classification system to examine the effects of different factors on the production of food loss and waste (FLW) across various phases of the food supply chain (FSC). In their study, (Canali et al., 2016) underscored that the origins of food loss and waste (FLW) cannot be attributed to a singular or limited number of fundamental factors. Instead, FLW emerges from an intricate web of interconnected causes that exhibit significant diversity. According to (Diaz-Ruiz et al., 2019), there is an overestimation of the potential of multidimensional methods, such as a comprehensive FSC viewpoint, in addressing the core of the food loss and waste (FLW) problem.

2.2. Fruit and vegetable waste and loss and sustainable development

Numerous local, regional, and global studies have effectively measured the resources and environmental consequences associated with food loss and waste (FLW). According to (Kummu et al., 2012), FLW constitutes more than 25% of the worldwide water, land, and fertilizer resources used in food crop production. The region including North Africa, West Asia, and Central Asia, which exhibit the lowest per capita water availability, demonstrates the third most significant rate of water loss and wastage (33%). This percentage is surpassed only by North America and Oceania (35%) and Latin America (34%). The region in question is heavily dependent on irrigation practices, resulting in a substantial water consumption per unit of food production-. In the context of China, a country grappling with significant land and water scarcity issues, (Liu et al., 2013) conducted a study that revealed the substantial impact of food loss and waste (FLW) on water and land resources. Specifically, their findings indicate that FLW contributed to over 20% of the overall water footprint, amounting to around 135.0 ± 59.7 billion cubic meters, as well as 25.7 ± 10.9 million hectares of land

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footprint in food crop production during the year 2010 (Liu et al., 2013). According to the findings of Song et al. (2015), household food waste in China contributes to about 2.7% (equivalent to 18 m3 per capita) of the country's annual water footprint (WF) resulting from food consumption. These calculations were based on survey data collected between 2004 and 2009. Their study further revealed that a significant proportion of food waste, namely 44%, consisted of water-based products, even though animal-derived goods accounted for just 13% of the overall trash. In 2008, the agricultural water footprint (WF) of the United Kingdom (UK) was impacted by needless home food waste, which constituted around 7.5% (equivalent to 89 cubic meters per capita) of the total. FLW exhibits adverse externalities, including the production of greenhouse gases, contamination of air and water, and the depletion of biodiversity, alongside the utilization of input resources (Muth et al., 2019). The issue of greenhouse gas (GHG) emissions stemming from food loss and waste (FLW) has garnered significant scrutiny. FLW plays a role in the generation of greenhouse gas (GHG) emissions through its Forest Stewardship Council (FSC) procedures and its management of food waste, which includes practices such as landfilling and composting. According to comprehensive research conducted by the Food and Agriculture Organization (FAO), the carbon footprint of food loss and waste (FLW) in 2007 was estimated to be around 3.3 gigatonnes of carbon dioxide equivalent (Gtonnes CO2 equiv) (Brancoli et al., 2017). This value represents approximately half of the total greenhouse gas (GHG) emissions produced by the United States during the same year. According to (Jia et al., 2023), waste disposal along the FSC was responsible for around 20% of FLW's carbon effect. Several national studies have investigated the carbon footprint of food loss and waste (FLW) in different countries. For instance, (Abeliotis et al., 2015) evaluated the FLW carbon footprint in Greece, while (Omolayo et al., 2021) assessed the Life Cycle Analysis of FLW. (Bernstad Saraiva Schott & Andersson, 2015) conducted a study on Sweden, while (Song et al., 2015) explored the FLW carbon footprint in China. In 2007, the United Kingdom's greenhouse gas (GHG) emissions resulting from avoidable and potentially avoidable food and beverage waste at the household level constituted approximately 25.7 million tonnes of carbon dioxide equivalent (CO2 equiv) (Chapagain & James, 2013). This equates to an average of 428 kilograms of CO2 equiv per person. These emissions accounted for 3% of the total GHG emissions in the UK, which is significantly higher than the corresponding emissions from Chinese households, differing by an order of magnitude. In 2009, the United States experienced a contribution of 2% to its net greenhouse gas (GHG) emissions due to avoidable food waste, which amounted to 368 kg CO2 equivalent per person. Insufficient emphasis has been placed on other environmental consequences associated with food loss and waste (FLW), specifically pertaining to water quality and eutrophication (Read et al., 2020).

For example, FLW is twice as high in the United States of America as in China, even though developing countries need more attention on this subject. Minimising FLW is critical for its economic, societal, ecological, and health-related impacts. According to ReFED, this impact would be significant and rapid. Reducing FLW would improve the economy (producer income, consumer expenses), food security, the fight against hunger, and the global environmental footprint. This paper explores how FLW management can help achieve the SDGs by 2030 based on the food related issues mentioned above. This paper aims to provide theoretical insights into decreasing food waste production by achieving one aspect of SDG number 12: Sustainable Consumption and Production.

2.3. Practices for managing FLW

Lean Practices for Food Loss and Waste (FLW) Management: Lean practices are centered around the minimization of waste and the maximization of value generation. Within the domain of fruit and vegetable (F&V) supply chains, scholarly investigations have been conducted to examine the potential benefits of incorporating lean principles, such as continuous improvement, customer focus, and flow management, into the handling and distribution processes of F&V (Affognon et al., 2015; Buzby & Hyman, 2012). These practices aim to mitigate inefficiencies, enhance transportation procedures, and guarantee punctual delivery, thereby diminishing potential causes of fruit and vegetable waste and loss.

Green practices: Green practices prioritize environmental stewardship and strive to reduce the ecological impact of supply chain operations. Esparza and colleagues (2020) emphasized various strategies for the utilization of fruit and vegetable waste, which encompass the extraction of bioactive compounds, the production of enzymes, the synthesis of bioplastics, and the generation of biofuels. Through the conversion of waste into valuable products, these practices significantly contribute to reducing waste and the sustainable utilization of fruit and vegetable byproducts.

Circular practices for fruit and vegetable waste reduction prioritize the principles of a circular economy, which involve the reuse of resources and the minimization of waste generation. Dora et al. (2020) put forth a set of measures aimed at facilitating the reuse, reduction, recycling, and recovery of fruit and vegetable (F&V) waste in the context of the potato supply chain. Implementing circular strategies facilitates the establishment of closed material

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loops, thereby fostering sustainable ecosystem development. This approach involves the conversion of waste into valuable inputs, consequently mitigating the demand for fresh resources.

Sustainable Practices in Food Loss and Waste Management: Sustainable practices encompass the comprehensive evaluation of social, economic, and environmental aspects within the realm of supply chain activities. Mena et al. (2011) categorized the factors contributing to fruit and vegetable waste into three main groups: megatrends, natural constraints, and management root causes. By acknowledging and addressing these underlying factors, professionals in the field can improve the management of fruit and vegetable waste while reducing the adverse effects on society and the environment.

Technological advancements in managing food loss and waste (FLW) are becoming more prevalent as strategies to enhance the handling of fruits and vegetables (F&V) waste. Several research studies have employed methodologies such as interpretive structural modeling (ISM), total interpretive structural modeling (TISM), and decision-making trial and evaluation laboratory (DEMATEL) to evaluate the interconnectedness between causes and challenges related to food loss and waste (FLW) (Gardas et al., 2017; Balaji and Arshinder, 2016). These technological methodologies assist in identifying crucial factors and priorities for managing food loss and waste.

The adoption of a holistic approach incorporating lean, green, circular, and sustainable practices has been shown through research to hold significant promise in mitigating the issue of food and vegetable waste and loss. Through an examination of the interconnections and collaborative effects of these methodologies, a holistic approach can be formulated that effectively tackles pressing obstacles and harmonizes with the overarching goals of sustainable development (Diaz-Ruiz et al., 2019).

Table 1. LGCS practices for fruit and vegetable loss and waste management factors

Lean Practices			**Source**
Inventory optimization	L1	Optimize inventory management to reduce overstocking and minimize waste. **(L1)**	(Proença et al., 2022; Quiroz-Flores et al., 2022)
Timeliness delivery	L2	Implement just-in-time delivery to ensure freshness and minimize spoilage. **(L2)**	(Ellison et al., 2022; McKone et al., 2001)
Accurate forecasting	L3	Use data analytics to forecast demand accurately and adjust supply accordingly. **(L3)**	(Gružauskas et al., 2019; Møller Christensen et al., 2021)
Green Practices:			
Eco-friendly packaging	G1	Embrace eco-friendly packaging solutions,	(Zeng et al., 2021)

		such as biodegradable or compostable materials. **(G1)**	
Energy efficient transportation	G2	Opt for energy-efficient transportation methods to reduce carbon footprint. **(G2)**	(Kumar, Sharma, et al., 2022; Paritosh et al., 2017)
Efficient irrigation system	G3	Implement water-saving irrigation techniques for farming operations. **(G3)**	(Wu et al., 2019)
Circular Practices:			
Local purchasing	C1	Establish partnerships with local composting facilities to turn organic waste into valuable compost. **(C1)**	(Fuchs & Glaab, 2011; Kumar, Raut, et al., 2022)
Waste recovery reuse	C2	Explore options for turning waste into byproducts, such as creating natural fertilizers or animal feed. **(C2)**	(Halloran et al., 2014; Joshi & Visvanathan, 2019)
Building a close loop system	C3	Consider setting up closed-loop systems where waste from one part of the supply chain becomes a resource for another. **(C3)**	(Kazancoglu et al., 2020; Kumar, Sharma, et al., 2022; Nayal et al., 2021)
Sustainable Practices:			
Sustainable firming	S1	Promote sustainable farming methods that prioritize soil health and biodiversity. **(S1)**	(Serebrennikov et al., 2020)
Education and training	S2	Educate consumers about the importance of reducing food waste and encourage responsible consumption. **(S2)**	(Amicarell et al., 2021; Thyberg & Tonjes, 2016)
Energy efficient storage facility	S3	Implement energy-efficient technologies, like solar panels, in processing and storage facilities. **(S3)**	(de Sadeleer et al., 2020)

In recent times, authors have employed multidimensional analyses to evaluate the causes of food and livelihood insecurity within food systems and value chains. Their objective is to uncover connections and determine the relative importance of these causes. In their study, Gardas et al. (2017) employed a combination of methodologies including ISM (Interpretive Structural Modeling), TISM (Total Interpretive Structural Modeling), AHP (Analytic Hierarchy Process), and DEMATEL (Decision-Making Trial and Evaluation Laboratory) to examine the interconnections among causes of food loss and waste (FLW), barriers to sustainable practices, and key performance indicators within the fruit and vegetable supply chain in India. Ongoing endeavours persist in directing attention towards the cessation or mitigation of food loss and waste (FLW), wherein various strategies, including reuse, reduction, recycling, and recovery, have been devised to curtail inputs and establish closed nutrient loops within a potato supply chain. The study conducted by Esparza et al. (2020) investigated strategies for utilizing waste generated from fruits and vegetables. Several promising methods have been discovered for achieving this objective, including the extraction of bioactive components, enzymatic synthesis, production of exopolysaccharides, manufacturing of bioplastics and biopolymers, and generation of biofuels.

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2.4. Research Gap

In recent years, there has been a notable increase in the focus on addressing wastage and losses in fruit and vegetable supply chains from a sustainable development perspective (Gardas et al., 2019). The current body of literature has extensively examined different individual practices, such as lean, green, circular, sustainable, and technological approaches. However, there is still a lack of comprehension regarding how these practices are interconnected and the implications they have within specific contexts. This study aims to address the existing gap in knowledge by conducting a thorough analysis that considers the complex relationships and interconnections among these practices. The goal is to develop a comprehensive framework that promotes waste reduction and sustainable development in fruit and vegetable supply chains. Previous research has focused on analyzing the advantages and difficulties associated with implementing specific practices. However, there is a dearth of comprehensive studies that explore the interplay and potential synergies among these practices within the distinctive framework of fruit and vegetable supply chains. There exists a necessity to conduct a more comprehensive examination of the structural connections between these practices, revealing their respective significance and influence on the mitigation of wastage and losses. In addition, an exhaustive comprehension of the contextual factors that impact the acceptance and incorporation of these practices in various supply chain environments is necessary.

3. **Research Methodology**

The existing literature also lacks an exploration of the incorporation of the total interpretive structural modelling (TISM) approach in analysing the interaction between these practices. Although the application of TISM has been observed in different supply chain contexts, its utilization in examining lean, green, circular, sustainable, and technological practices within the fruit and vegetable supply chain has not been extensively explored. The objective of this study is to address this research gap by utilizing Total Interpretive Structural Modeling (TISM) as a methodology to identify the causal relationships and hierarchies among these practices. TISM will offer a more comprehensive understanding of how these practices can be effectively implemented and integrated, thereby providing a more structured approach to their implementation.

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By considering both direct and indirect influences among the components, TISM provides a more accurate and comprehensive perspective of the system. As it only considers direct influences, ISM may overlook some significant influences or effects that depend on other factors. The TISM also aids in comprehending the linkages or arrows that bind the elements or nodes together. Links between the components are displayed along with their type and direction, which can help with system understanding and explanation. Links in ISM are meaningless, which might make the system harder to comprehend. The transitivity rule used by TISM, which uses a pair-wise comparison matrix that is simplified and requires fewer comparisons, allows it to handle huge, complicated systems with numerous components and relationships. ISM can be challenging and time-consuming to manage because it necessitates several comparisons and expert decisions.

3.1. *The Total Interpretive Structural Model (TISM),*

i. Total Interpretive Structural Modeling (TISM) is a method for figuring out how various elements or variables interact in a complicated system. It is a development of Interpretive Structural Modeling (ISM), which exclusively assesses the direct interconnections between the elements. To provide the system with more information and interpretations, TISM also assesses indirect or transitive relationships. The steps in the TISM methodology are as follows:

ii. Identifying significant aspects or variables through literature review and interaction with academic experts.

iii. Determining the contextual link between the factors, which defines how one factor influences or affects another in the system called SSIM. This is accomplished using a triangular comparison matrix, in which each factor is compared to every other factor and assigned a symbol that denotes the nature and direction of the relationship. The symbols are as follows:

- V: Factor A leads to factor B
- A: Factor B leads to factor A
- X: Factors A and B influence each other
- O: Factors A and B are unrelated

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iv. Transforming the SSIM comparison matrix into an initial reachability matrix which shows how the factors are linked directly and indirectly. The following rule has been used in the table to change SSIM to IRM.

v. After getting the initial reachability matrix, the transitivity rule was used. This rule says that if path A leads to path B, and path B leads to path C, then path A also leads to path C. The reachability matrix is a binary matrix where 1 means a connection and 0 means there is no connection.

vi. Divide the reachability matrix into different levels that show the order of the system's factors. This is done by figuring out how much each factor drives the other factors and how much they depend on each other. Driving power is the number of factors, including itself, that a given factor influences or affects. Dependence is the number of things that affect or influence a certain thing, including that thing itself.

vii. Put the driving power and dependence of each factor on a two-dimensional graph, called a driving power-dependence diagram or MICMAC plot. Based on where they are on the graph, this diagram helps to divide the factors into four groups. These are the groups:

Autonomous: factors that don't need to be driven or depended on much. They have a weak link to the system and don't have much of an effect on it. Dependent: factors that don't do much on their own but depend on other things. They are strongly affected by other things, but they don't have much power over them. Linkage: factors that have a lot of influence and depend on other things. They are closely linked to other things and influence each other. Independent: factors that have a lot of power but don't depend on other things. They are the most important parts of the system and have a lot of power over the other parts.

viii. Making a directed graph or network diagram that shows how the different parts of the system are organized and how they relate to each other. This is done by taking the levels from the reachability matrix and putting arrows between them to show how they relate to each other in the context.

3.2. Data collection

The data were gathered through interviews conducted with a panel of five experts who possess extensive expertise in the industrial area, specifically in agrifood loss and waste management. Experts have over 15 years of expertise in the respective sector. The panel consists of three industry experts specializing in the agrifood sector, together with two individuals with an academic background. Each member of the panel possesses a minimum of 15 years of professional experience. All five - experts originated from India and possessed doctoral degrees in the field of agrifood supply chain management. The objective of the interview has been explained along with an explanation of the selected practices derived from relevant literature. The link between each pair was thoroughly examined, and after that, the SSIM matrix was constructed following the consensus of experts.

4. **Result Analysis**

4.1. TISM

Step 1 Development of SSIM matrix

SSIM matrix has been developed and provided in the table. The SSIM matrix has been developed through conducting brainstorming sessions with a panel of five experts with high experience in the agrifood supply chain. The outcomes of the brainstorming session helped to fill the SSIM matrix.

Table 2 SSIM matrix

	G2	L3	S3	C2	S1	G1	L2	C1	C3	G3	L1	S2
G2	X	A	A	A	O	O	V	V	V	V	A	O
L3		X	V	O	V	O	V	V	V	O	V	V
S3			X	V	O	O	O	O	O	A	O	A
C2				X	V	V	V	O	V	O	V	V
S1					X	O	A	V	O	A	O	O
G1						X	O	V	A	V	O	O
L2							X	A	V	O	A	O
C1								X	O	O	O	V
C3									X	V	A	V
G3										X	A	A
L1											X	V
S2												X

Step 2 Preparation of initial relational matrix.

The SSIM matrix has been converted into the binary digit according to the rule discussed and shown in the table.

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Table 3 IRM matrix

	G2	L3	S3	C2	S1	G1	L2	C1	C3	G3	L1	S2
G2	1	0	0	0	0	0	1	1	1	1	0	0
L3	1	1	1	0	1	0	1	1	1	0	1	1
S3	1	0	1	1	0	0	0	0	0	0	0	0
C2	1	0	0	1	1	1	1	0	1	0	1	1
S1	0	0	0	0	1	0	0	1	0	0	0	0
G1	0	0	0	0	0	1	0	1	0	1	0	0
L2	0	0	0	0	1	0	1	0	1	0	0	0
C1	0	0	0	0	0	0	1	1	0	0	0	1
C3	0	0	0	0	0	1	0	0	1	1	0	1
G3	0	0	1	0	1	0	0	0	0	1	0	0
L1	1	0	0	0	0	0	1	0	1	1	1	1
S2	0	0	1	0	0	0	0	0	0	1	0	1

Step 3 Transitivity check and preparation of final reachability matrix

Transitivity check has been performed manually by checking the relationship. A transitivity relationship is present if A is related to B and B is related to C, then A and C should have a relationship. All non-relationship values are checked and marked as bold numbers if there is a transitivity relationship. The final relationship matrix is shown in the table.

Table 3 Final relationship matrix

	G2	L3	S3	C2	S1	G1	L2	C1	C3	G3	L1	S2	
G2	1	0	**1**	0	**1**	**1**	1	1	1	1	0	**1**	9
L3	1	1	1	**1**	1	**1**	1	1	1	**1**	1	1	12
S3	1	0	1	1	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	11
C2	1	0	**1**	1	1	1	1	**1**	1	**1**	1	1	11
S1	0	0	0	0	1	0	**1**	1	0	0	0	**1**	4
G1	0	0	**1**	0	**1**	1	**1**	1	0	1	0	**1**	7
L2	0	0	0	0	1	**1**	1	**1**	1	**1**	0	**1**	7
C1	0	0	**1**	0	**1**	0	1	1	**1**	**1**	0	1	7
C3	0	0	**1**	0	**1**	1	0	**1**	1	1	0	1	7
G3	**1**	0	1	**1**	1	0	0	**1**	0	1	0	0	6
L1	1	0	**1**	0	**1**	**1**	1	**1**	1	1	1	1	10
S2	**1**	0	1	**1**	**1**	0	0	0	0	1	0	1	6
	7	1	10	5	12	8	9	11	8	11	4	11	

Note: bold values show transitivity relationship

Step 4 Level partitioning and development of TISM diagraph

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The level partitioning step has been performed by computing the antecedent set, reachability set and interaction set for each practice. By comparing the antecedent set and reachability set

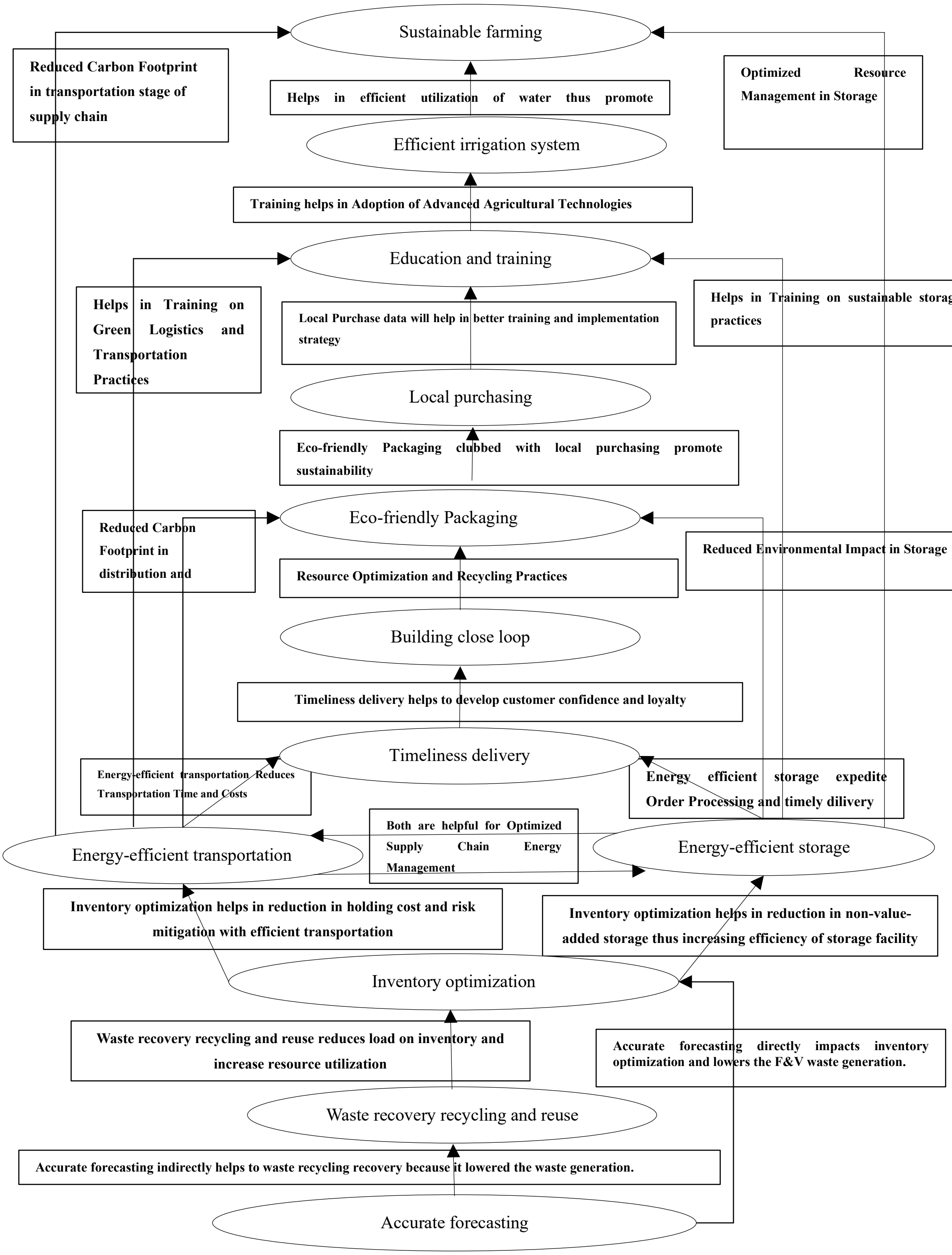

Figure 1 TISM structural hierarchical model

interaction set is prepared that shows all the relationships that are the same in both. By comparing the antecedent set and interaction set practices whose relationship value is the

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same are selected as first level practice and removed from the system for the next step computation and repeat the same till the selection of the last practice. A TISM interrelationship diagram has been prepared based on the relationship and level of practices shown in Figure 1.

Figure 1 of the TISM hierarchical structural model shows several strategies that help to link the two practices of food waste reduction. Practices like accurate forecasting and waste recovery, recycling and reuse are the two practices placed at the bottom of the hierarchy, indicating the most important practice to watch out for waste management towards sustainable development. These two practices are linked because an accurate forecasting strategy indirectly helps in waste recycling recovery as it lowers waste generation throughout the supply chain. Sustainable farming and advanced irrigation systems are the top two practices in the hierarchy.

4.2. MICMAC analysis

Dependence and driving power for each practice have been computed by counting the total relationship drive and driven. The driving power of the practice is computed by counting the practices they influence. However, dependence power computed by counting the dependent relationship means how much practices affect them. The graph between dependence power (X-axis) and driving power (Y-axis) has been plotted to perform MICMAC analysis. In the four quadrants of the MICMAC plot, 1st quadrant of low DEP power and low DRV power, called autonomous culture, has very little significance and may neglected from the study. The findings of this study show no practices found in 1st quadrant. Three practices, Inventory optimization L1, Accurate forecasting L3 and Waste recovery reuse C2 are grouped in an independent cluster in the MICMAC plot. Efficient irrigation systems and education and training are placed in the boundary of dependent and linkage clusters in the MICMAC plot, however in the ISM structural model, these two are placed at the bottom of the hierarchy, hence these two should be considered as dependent group practices.

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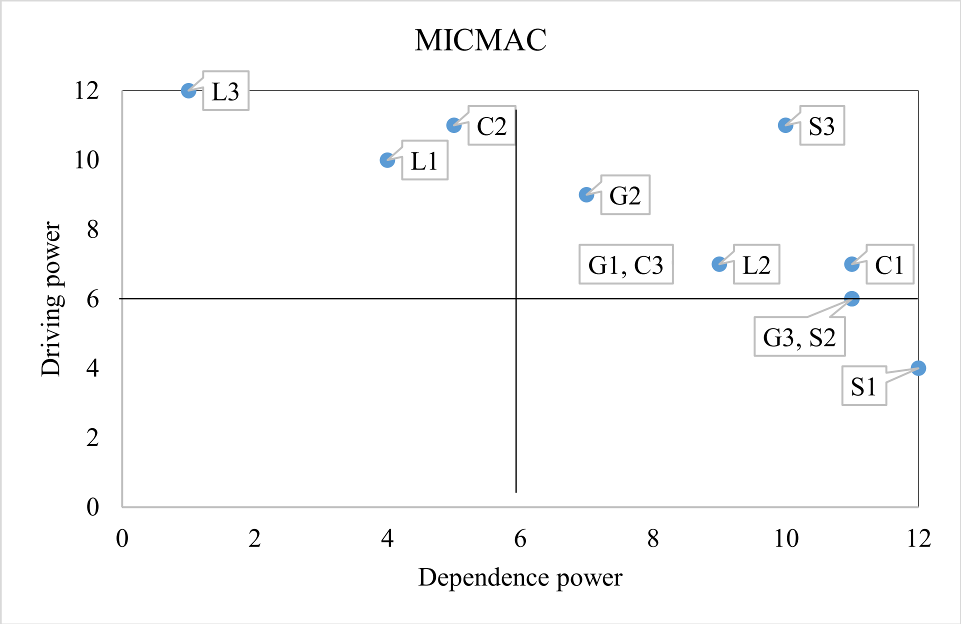

Figure 2 MICMAC analysis

5. **Result Discussion**

5.1. Discussions

Practices Inventory optimization L1, Accurate forecasting L3 and Waste recovery reuse C2 are grouped in independent clusters in the MICMAC plot and are also available in the bottom level hierarchy in the TISM structural model. The bottom level practices are important and independent in nature, which is also clear from the MICMAC plot and mainly act as the cause of the system that drives the whole system. Accurate prediction in the food supply chain is essential for reducing food waste and improving the efficiency of recovery, recycling, and reuse practices. Through the accurate anticipation of demand, firms can minimize excessive production, enhance inventory control, and effectively synchronize supply with consumer requirements. Demand Forecasting and precise prediction aid in anticipating the true demand for food goods, thereby minimizing excessive production. When production is better synchronized with demand, the probability of having surplus inventory and resulting waste is reduced. Improved forecasts enable organizations to optimize inventory management, assuring the timely sale and consumption of perishable commodities within their designated shelf life, hence minimizing food waste. Precise data regarding the volumes and categories of waste can enhance the effectiveness of recycling processes, as facilities can make necessary preparations for the particular types of waste they will handle. Forecasting can help uncover potential opportunities for repurposing products that would

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otherwise be discarded, such as utilizing unsold vegetables in the creation of prepared meals or as animal feed. Precise forecasting plays a crucial role in supporting broader circular economy activities by minimizing waste and enabling efficient recovery and recycling processes. These programs strive to maximize the utilization of resources for as long as possible.

Recovery and recycling are crucial elements of inventory efficiency, particularly in industries that handle perishable items and other time-critical products. These methods aid firms in properly managing their inventory by minimizing waste, optimizing resource use, and boosting overall efficiency in the supply chain. Recovery and recycling are essential for optimizing inventory by reducing waste, maximizing resource usage, improving the efficiency of the supply chain, and producing cost savings. These techniques not only promote environmental sustainability but also enhance the resilience and flexibility of the inventory management system. Companies may optimize their inventory management and improve their supply chain performance by incorporating recovery and recycling practices into their operations. This allows them to align their inventory with demand more effectively, cut expenses, and enhance overall efficiency. Efficient inventory management is crucial for assuring the prompt delivery of perishable food items, hence minimizing food waste. Businesses can greatly enhance the efficiency of their perishable food supply chains by precisely predicting demand, improving visibility, effectively managing stock rotation, optimizing distribution networks, and maintaining rigorous temperature control. Utilizing cutting-edge technologies and promoting cooperation throughout the supply chain also improves these endeavors, thereby leading to a more environmentally friendly and streamlined food system. Major retail conglomerates such as Walmart and Tesco employ advanced inventory management systems to guarantee the timely delivery of perishable food products to their stores, hence minimizing loss caused by spoilage. Companies such as Amazon Fresh and Instacart depend on sophisticated logistics and inventory optimization techniques to guarantee the fast and effective delivery of perishable goods to clients.

Inventory optimization is a methodological strategy to effectively manage stock levels, ensuring that the appropriate quantity of inventory is accessible to fulfill consumer demand while minimizing expenses and inefficiencies. Inventory optimization has a notable advantage in improving the efficiency of transportation and storage facilities in terms of energy consumption. Companies can minimize the requirement for excessive storage space by ensuring that they maintain adequate inventory levels. This reduces the amount of energy

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needed for illuminating, warming, cooling, and upkeeping extensive warehousing buildings. Efficient inventory management enables the utilization of storage space, minimizing the requirement for many storage sites and consolidating items into fewer, more energy-efficient facilities. Inventory optimization typically entails utilizing sophisticated analytics and routing technologies to devise the most efficient delivery routes. This minimizes the distance covered, fuel usage, and release of greenhouse gases related to transportation. Through the synchronization of inventory levels with demand, organizations can streamline shipments, thereby minimizing the number of trips required for transporting goods. Reduced travel results in decreased fuel consumption and emissions.

The TISM framework considers efficient irrigation systems and education and training to be dependent practices. Education and training are essential for constructing effective irrigation systems. They improve the understanding and abilities needed to create, execute, and sustain these systems, encourage the use of cutting-edge technologies, and support the development of environment-friendly water management methods. Through the allocation of resources towards education and training, it can be guaranteed that irrigation systems are not only highly effective but also economically feasible and ecologically sustainable. Education programs can provide farmers and system managers with information regarding water use regulations and policies, thereby assuring adherence and encouraging the adoption of sustainable water management techniques. Training has the potential to enable individuals to actively support and promote the implementation of effective water management policies, as well as actively involve themselves in their communities to encourage the adoption of efficient irrigation systems.

6. **Conclusion**

The present research examines the contextual analysis of lean, green, circular, and sustainable practices in the fruit and vegetable supply chain with the aim of managing wastage and losses, ultimately contributing to sustainable development. This study carries significant implications for both the academic and industrial sectors. TISM methodology has been utilised to explore the contextual relationship among the practices and the application of the MICMAC analysis explores the practices into various groups. Three practices, Inventory optimization, Accurate forecasting, and Waste recovery reuse are grouped in an independent cluster in the MICMAC plot. Efficient irrigation system, Sustainable farming, and education and training are placed in dependent clusters, except these all are grouped in linkage clusters. This research has various theoretical and practical implications discussed below.

6.1. Research Implication

6.1.1. Theoretical implications

The present study makes a valuable contribution to the current academic literature by elucidating the intricate network of interconnections and causal dynamics among various practices within the supply chain of fruits and vegetables. This study contributes to the existing body of knowledge by employing the ISM approach to examine the strategic integration of practices for sustainable waste reduction, thereby enhancing theoretical understanding in this area. The present study has resulted in the development of an integrated conceptual framework that provides a comprehensive perspective for researchers to examine and assess the incorporation of various practices within the domain of supply chain management. The above concept functions as a fundamental basis for the formulation of models and theories that effectively encompass the comprehensive essence of sustainable development within intricate supply chain contexts. The utilization of the ISM approach to examine the causal relationships among these practices represents a significant methodological advancement in the realm of supply chain research. This novel approach allows researchers to visually depict the hierarchies and interconnections, thereby facilitating a more lucid understanding of the adoption and integration of practices.

6.1.2. Practical implications

The results of this study provide experts with a framework for making strategic decisions pertaining to the implementation and incorporation of lean, green, circular, sustainable, and technological practices. Organizations have the potential to enhance their prioritization of efforts and allocation of resources to attain heightened efficacy in waste reduction and the implementation of sustainable supply chain practices. Operational efficiency can be enhanced through the utilization of insights obtained from this research, which can effectively identify key areas requiring intervention for operational improvements. Organizations have the capacity to identify pivotal practices that, when effectively incorporated, result in heightened operational efficiency, diminished resource wastage, and decreased environmental footprint. The focus of this study on sustainable development is in accordance with the worldwide sustainability agenda, exemplified by the United Nations' Sustainable Development Goals (SDGs). Organizations could employ the integrated framework to harmonize their practices

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with these objectives, thereby making a positive contribution to wider societal and environmental aims. The promotion of stakeholder collaboration is facilitated by comprehending the interconnectedness of diverse practices within the fruit and vegetable supply chain. Producers, suppliers, distributors, retailers, and policymakers have the potential to collaboratively strive for the establishment of a supply chain system that is both sustainable and efficient. Inventory optimization plays a critical role in enhancing energy efficiency within transportation and storage facilities. By reducing excess inventory, improving transportation efficiency, enhancing load planning, and enabling better temperature control, companies can significantly lower their energy consumption and environmental impact. The integration of advanced technologies and green practices further amplifies these benefits, leading to a more sustainable and energy-efficient supply.

6.1.3. The policy implications.

Policy Formulation: Policymakers could utilize the knowledge acquired from this research to develop and implement policies that effectively promote the adoption of integrated practices within the fruit and vegetable supply chain. These policies have the potential to provide incentives for organizations to embrace sustainable practices, thereby making a positive contribution towards the reduction of waste and the conservation of the environment. Regulatory Frameworks: The utilization of the study's findings by regulatory bodies can facilitate the establishment of regulatory frameworks aimed at fostering sustainable practices within the fruit and vegetable supply chain. These frameworks possess the capacity to provide guidance for industry practices, ensure adherence to regulations, and foster the advancement of sustainability.

7. **Future research direction**

This research has several aspects for the future, such as the cause effect relationship along with the intensity among the practices may be identified. The findings of this study may be used as a policy framework to reduce food waste and improve the sustainable performance of the food supply chain. The relationship shown in the TISM hierarchy may be validated through hypothesis testing. A more diverse range of expert opinions may be gathered to compare the TISM model.

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