**The interplay effects of digital technologies, green integration, and green innovation on food supply chain sustainable performance: an organizational information processing theory** **perspective**

**Abstract**

Green integration (GIT) and green innovation (GIO) in food supply chains (FSCs) have the potential to attain sustainability with the facilitation of digital technologies (DTs). Nevertheless, few studies have been conducted regarding the effectiveness of DTs and GIT in determining GIO and sustained FSC. Furthermore, an unsustainable food supply chain is a globally recognised problem that needs immediate, multidimensional holistic measures. Therefore, the present study tests the interplay effects of GIT, GIO, and DTs in FSC sustainable performance (FSCSP) under the strategic configuration for information-processing fit, i.e., organizational information processing theory (OIPT) perspective. Acombined approach of structural equation modelling (SEM) and artificial neural network (ANN) was used to examine the collected responses from different related industries and validate the robustness of the proposed hypothesis through ANN. The findings demonstrate that the usage of DTs has a favourable impact on GIO and GIT. Furthermore, GI has a positive influence on GIO. Finally, both GIO and GI have a positive impact on FSCSP. Theoretically, under the strategic alignment for information-processing fit, the study’s findings suggest that GIT and GIO improve their FSC strategies and practically keep the FSC ahead of the competition for the long haul by ensuring sustainability. It is clear from the results of this research that practitioners should support more DTs to promote GIT, GIO, and FSCSP. This research fills a significant gap in the literature by analyzing the unexplored connections across the FSCSP, GIT, GIO, and DTs as facilitators in the context of sustainability.

***Keywords:*** Digital technologies; Green integration; Green innovation; Food supply chain; Sustainable performance; Artificial Neural Network.

**1. Introduction**

The food business, which has an immediate consequence on communities, is crucial to the local and worldwide economies. For instance, the food business contributed to 8% of the EU's GDP (Zhu et al., 2018). Greater market uncertainty and costs are two effects of rising food demands, mostly driven by population and income rise (Calvin et al., 2020), which puts more strain on already-scarce environmental assets like fresh water, farming lands, and energy (Hasegawa et al., 2021). It immediately demands alternative food supply chain management (FSCM) approaches, which build a sustainable balancing approach via the triple bottom line by concurrently incorporating economic, environmental, and social factors (Zhu et al., 2018). The term "FSCM" refers to those processes that ensure the nutritional value and hygiene of a range of food items that are included in the food chain in a highly productive and economical manner, beginning with manufacturing, transportation, and completing with customer consumption (Sharma et al., 2020).

The FSCM nowadays must deal with problems including increasing energy utilization, Greenhouse Gas (GHG) emissions, and numerous financial and socio-challenges. Because of the life cycle assessment of food commodities, energy is a major factor. For instance, almost one-third of the world's food production is lost or misused, which accounts for 38% of the fossil fuels used in the world food industry (United Nations, 2022). 31% of world pollution in the past decade has come from GHG emissions from agri-food industries, which include modifications to land use, farming operations, and pre-and post-food manufacturing procedures such as energy usage, packaging, fertilisers, and waste management (FAO, 2021).

Furthermore, an effective transportation infrastructure is required because of the significant possibility of quality degradation associated with food commodities having a limited shelf life. Finally, corporate responsibility programmes like fair trade and subsidiarity may have an impact on how a specific FSC runs (Govindan et al., 2018). With 1.2 billion consumers, India has a sizable food processing sector. The country's marketplace for food is the sixth-biggest in the world, and its food processing industries account for 32% of the nation's overall food revenue. The industry ranks fifth in phrases of productivity rate, usage rate, global trade, and revenue generation (Ministry of Food Processing Industries, MOFPI, Government of India). Its gross value added (GVA) goes towards the agro-based societal business at 8.39% and the production business at 8.80%. The food processing industry contributes roughly 13% of Indian exports and constitutes 6% of all industrial sector investments (Sharma et al., 2020).

As a result, Indian food firms are under enormous strain to adopt innovative approaches that concentrate on sustainable development instead of conventional strategies that exclusively emphasize productivity and profitability (Oskarsodottir and Oddsson, 2019). This significant policy shift is pushing corporations to develop a win-win approach to reduce the tensions between ecological and financial success (Bilali and Allahyari, 2018).

Studies have proposed using Green Innovation (GIO) as a tactical strategy to ensure sustainable growth while gaining competitiveness (Liu, 2020). Green innovation is defined as the creation of environmentally friendly goods or procedures that have fewer negative effects on the environment, with the aim of conserving energy and resources as well as preventing waste and pollution, recyclable, and reused materials (Chen et al., 2006; Li et al., 2019). GIO has the potential to successfully tackle the increasing climate issues and sustainable needs (Al-Khatib, 2022).

Due to its focus on differentiated products, alternative marketplace access approaches, cost-saving methods, and advanced managerial skills, GIO is a promising strategy for simultaneously attaining economic and sustainable development (Qu and Liu, 2022). By increasing product quality, GIO may increase resource efficiency while offsetting the additional expenses associated with environmental initiatives ([Aftab](https://scholar.google.com/citations?user=rOI9A8kAAAAJ&hl=en&oi=sra) et al., 2022). Thus, organizations must adopt GIO in the current corporate context if they want to succeed economically and environmentally. Due to mounting environmental strain, GIO is one of the crucial strategies for achieving sustainable performance in the food sector (Chang, 2011). Customer-focused businesses must put interaction with customers first and focus on efficiently utilising data to meet their specific needs if they are to successfully implement green innovation. Green innovation relies heavily on base technology, which includes cutting-edge technologies like big data, cloud, IoT, and AI (Sharma et al., 2020; Lerman et al., 2022). Additionally, front-end technology that improves green operations and contributes to FSC sustainability includes simulation, 3D printing, and augmented reality (Sharma et al., 2020; Lerman et al., 2022). Huge progress in fostering sustainable growth has been driven by rapidly expanding digital technologies (Liu et al., 2020). As digital technologies link suppliers and consumers, competent digitization greatly supports supply chain Green Integration (GIT) and offers a foundation for enhancing an enterprise’s capacity for GIO (Green et al., 2012; Liu et al., 2018). Green Integration (GIT), emphasizes recycling wastage, pollution control, energy conservation, and adopting a framework for environment monitoring (Eiadat et al., 2008). Thus, GIT is the “collaboration and coordination among all partners in the food supply chain for the mutually sustainable practices inside and outside the organization, which comprise of three dimensions such as internal, supplier and customer integration.” Although numerous researchers have found a favourable correlation between green innovations and food supply chain green integration (FSCGIT) (Aslinda Abu Seman et al., 2019; Wong et al., 2020), the interconnection between FSCGIT and an organization's capacity for GIO is still unclear (Sharma et al., 2017). Numerous findings have been prompted by this nascent green aspect in SCM to reconsider and re-evaluate various SCI-related attributes, including conceptual presumptions and interpretations of its influence on GIO and the interplay of multiple stakeholders throughout the entire FSC (Chen and Hung, 2014).

Sustainability within FSC encompasses manufacturing systems converting raw material into finished products, as well as the functionality of those systems which enables treatments after life cycle completion comprising of packaging returns, recycling, conservation of sources, reusability, refurbishment (Das and Chowdhury, 2012; León Bravo et al., 2021). Sustainability within SC operations practices is operation tactics, strategies and techniques which yield both economics and environmental-based goals (Gunasekaran et al., 2014; Di Prima et al., 2023). Thus FSCM is under increased strain to attain profitability and sustainability simultaneously (Zhu et al., 2018). According to research in organizational learning and strategy formulation, innovation is an approach that involves purposefully seeking out innovative insight and data, effectively controlling and assimilating numerous understandings from inputs, and effectively adapting the expertise to innovative goods or manufacturing procedures for creating value (Miller et al., 2007). Additionally, the quick development of digital technologies has made it possible to apply green practices more widely for green efforts primarily driven by technologies (Chiabai et al., 2013; Liu et al., 2018).

Despite significant research in FSCM and data management has been conducted, which has outlined the impact of SCI on firms’ performances from distinct viewpoints, the majority of such research has not articulated the impact of SCGI on GIO and sustainable performance (Zhu et al., 2018; Qu and Liu, 2022). Furthermore, most studies have paid attention only to innovation without focusing on diverse attributes of green process and product innovation ([Aftab](https://scholar.google.com/citations?user=rOI9A8kAAAAJ&hl=en&oi=sra) et al., 2022), as shown in Table 1 of Section 2.1. Given the identified gaps, the following research questions were formulated:

* *RQ1. How do the base and front-end digital technologies affect the performance of FSC-green integration (FSCGI) and FSC-green innovation (FSCGIO)?*
* *RQ2. How do FSCGI and FSCGIO contribute to leading FSC towards sustainability-associated performance?*

Further, to understand the connection between digital technologies, FSCGI, and FSCGIO, the model put forward in this research utilizes the organizational information-processing theory (OIPT) (Enrique et al., 2022). We used OIPT by adopting the work of Dalenogare et al. (2022) and thinking of digital technologies as a means of indicating the capability for information processing. The demand for information processing, on the other hand, is represented by GIO, which expects that improved GIO would result from more integrated data from the FSC. The SCGI is seen as information-boundary constraints that put the information-processing fit under strain. In order to eliminate uncertainty and optimization, OIPT addresses these challenges and recommends organizations increase their ability to successfully and quickly handle related information and expertise involved in GIO (Enrique et al., 2022). Organizations’ information-processing capability may be improved by integrating additional information-processing systems to handle the huge amount of uncertain data associated with GIO (Galbraith, 1973). Consequently, by analyzing how the configuration context between SCGI and digital technologies impacts GIO and sustainable performance, this research will fill in the gap and supplement previous research by checking the fit between SCI and base/front-end digital technologies in improving GI as well as sustainable performance. Further, by utilizing the OIPT and survey data, this study verifies the conceptual framework.

The research is structured as follows: Section 2 provides theory building and hypothesis formulation; Section 3 describes the research methodology; Section 4 explains the results; Section 5 offers discussions. Theoretical and practical implications are presented in Section 6, and conclusions, limitations, and future research direction are in the last section of the study.

**2. Theoretical background and formulation of hypotheses**

***2.1*** ***Organizational Information Processing Theory***

The Organizational Information-Processing Theory (OIPT) has been utilized to handle the dynamic organizational processes of learning (Galbraith, 1973; Grah et al., 2016). Each organization is viewed from the standpoint of OIPT as an information unit with a specific amount of processing capability (Enrique et al., 2022). Organizations must have a particular amount of information processing capabilities to meet the quantity and strength of data they must analyze to support efficient data gathering, storing, and transformations (Qu and Liu, 2022). Further, the quantity and quality of data are significantly correlated with the amount of uncertainty and risks (Galbraith, 1974). Usually, simple and repetitive tasks only generate a small amount of data, requiring a simple organizational layout with limited data computing capability. To prevent data congestion and accomplish efficient knowledge handling, a firm's information-processing capabilities must be expanded by adding peripheral vertical or horizontal information-processing elements to handle the increased volume of data and uncertainty associated with more complicated tasks (Galbraith, 1973). The features of GIO, such as complexity and uncertainty, influence the data processing required for this research. As was previously said, complicated green activities demand a significant amount of data and expertise. Moreover, it is extremely difficult to predict customers' needs and priorities for sustainable products due to the dynamic and quickly evolving green market (Corrocher and Zirulia, 2010). OIPT provides a way of improving data management capabilities for enhancing GIO without spending additional expenses (Enrique et al., 2022). Supply chain integration was examined in the setting of the digital shift by Dalenogare et al. (2022). They demonstrated how businesses may exchange real-time information from numerous locations and formats due to digital platforms. They observed that, according to the OIPT paradigm, the data-integration aspect of the supply chain's digital transformation may be seen as an information-processing phenomenon (Galbraith, 1974). As a result, the OIPT demand for this study is based on the complexity and ambiguities associated with green innovations. OIPT is also required for current research because of the large amounts of data and information associated with complicated digital data exchange through a variety of digital platforms (Qu and Liu, 2022). Further, we provide Table 1 to offer a brief summary of past work and their contribution to the literature along with the contribution of present research.

**Table 1:** Published studies in the direction of green innovation, SC integration and sustainable performance

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Study** | **Explanatory variables** | **Outcome variables** | **Theoretical**  **lens** | **Research type** | **Findings** |
| Wong et al. (2013) | Internal integration (II), External integration (EI) | Product innovation (PI) | Organizational information processing theory (OIPT) and Relational view theory (RVT) | Survey (151 automotive industry) | The survey statistics from the Thai automobile sector, complementary integration and EI are both positively related to product innovation, while II is unrelated. |
| Du et al. (2018) | Green customer integration, green supplier integration | Green innovation performance (GIP) | Resource dependence theory (RDT) | Survey (176 manufacturing firms) | The findings show that green innovation success is favourably correlated with green consumer integration, green suppliers’ integration, and their interplay. |
| Melander (2018) | Internal and external partners | Collaborative green product innovation | Not adopted any theory | Qualitative | This study focuses on the skills that businesses require from suppliers and consumers while working together to develop green products. |
| Yang et al. (2020) | Green SCM and green information system (GIS) | Economic (ECP), operational (OP), environmental (ENP) and social (SOP) performances. | Not adopted any theory | Survey (311 manufacturing and services firms) | Casual linkage among GSCM and GIS improves functional, social, environmental, and economic outcomes. |
| Shahzad et al. (2021) | Knowledge management process (KMP), and sustainable development practices (SDPs) | Corporate green innovation (CGI) | Resource-based view (RBV) theory | Survey (393 manufacturing firms) | Firstly, the parameters of the SDPs are considerably improved by the KMP elements (collection, distribution, and implementation) (environment, economic and social). Secondly, the SDP parameters are crucial for producing CGI. Third, the link between the KMP and CGI is somewhat mediated by the adoption of SDPs. |
| [Aftab](https://scholar.google.com/citations?user=rOI9A8kAAAAJ&hl=en&oi=sra) et al. (2022) | Corporate environmental ethics (CEE) and strategy (CES), Green innovation (GI), | Social, economic, and environmental performance | Not adopted any theory | Survey (335 manufacturing firms) | The outcomes reveal that GI mediates the interconnection between CEE and sustainable performance (SOP, ECP, and ENP). |
| Junaid et al. (2022) | Sustainable internal, supplier (SI), and customer (CI) integration, green managerial (GMI) and process (GPI) innovations. | firm’s financial performance | Information processing theory (IPT) and Dynamic capability view (DCV) | Survey (296 manufacturing firms) | The outcomes reveal that SI and CI foster both GMI and GPI. The results showed that GMI significantly improves the organization's financial performance. |
| Qu and Liu, (2022) | Supplier integration (SI), Customer orientation (CO) and green information system (GIS) | Green product and process innovation | Information-processing theory | Survey (231 Chinese firms’ SC) | Results confirm the significant role of SC integration in improving firms’ GI while aligning with an efficient GIS. |
| Lerman et al. (2022) | Digital SC, Green relationships and operations | Green performance (GP) | Configuration  approach | Survey (473 manufacturing firms) | The findings demonstrate how smart SC helps GP by handling green relationships (intra-firms’ green practices) and accomplishing green operations (inter-firm green practices). |
| Singh et al. (2022) | Stakeholder pressure, green innovation (GI) and green dynamic capability (GDC) | Finance and market performance | Stakeholder theory and Resource-based view (RBV) theory | Survey (248 SMEs manufacturing sector) | The study shows business performance is influenced by GI, GI is influenced by GDC, and GDC is influenced by the stakeholders’ pressure on the environmental aspects. |
| **Present Study** | Base and Front-end Digital Technologies, FSC Green Integration, FSC Green Innovation | FSC Sustainable Performance (SP) | Organizational information processing theory (OIPT) | Survey (268 Indian food businesses SC) | The results show that digital technologies have a favourable influence on green innovation and green integration. Green integration is positively impacted by green innovation. Finally, the SP of the food SC is positively impacted by both green innovation and green integration. |

**2.2 Hypothesis formulation**

Organizations have been utilizing base technologies to gather and evaluate information. It might open up innovative potentials for information monitoring and collaboration against sustainable development as digital SC integrates the utilization of base technologies (e.g., IoT, blockchain, and big data analytics) to enhance partnerships (Frank et al., 2019). The integration of green FSCM is carried out by front-end technologies, likewise, collaborative robotic systems, 3D printing, and augmented reality, using data that has been gathered and evaluated by base technologies. Because blockchain is a shared, immutable database, it may reinforce the relationships among participants in the food SC (Saurabh and Dey, 2021). Meanwhile, consumers may also take part in the agri-food circulatory footprints to gain knowledge regarding foodstuffs. Furthermore, participants can attain more noteworthy outcomes if Big Data technologies are employed (Liu et al., 2020).

Additionally, workers utilizing augmented reality might alter warehousing layout by instructing workers on better effective strategies to arrange and design the stores (Rejeb et al., 2021; Dornelles et al., 2022). In this respect, SCI was examined from the perspective of digitalization by Dalenogare et al (2022). They illustrated how core digital technologies allow corporations to exchange real-time information from numerous locations and forms. According to their argument, the FSC's digitalized data-integration features may be viewed as an information-processing event from the OIPT viewpoint (Galbraith, 1974). According to OIPT, an efficient base digital technology can significantly increase a firm's information-processing capabilities by offering an interface for simple data exchange and seamless connectivity systems between multiple operational elements inside the business and between the business and its distributors and clients (Enrique et al., 2022). Consequently, a digital FSC may significantly ease a firm's integration of green suppliers as well as its green consumers’ focus. Thus, a hypothesis may be proposed as:

***H1:*** *Digital technologies have a positive impact on food supply chain green integration.*

Companies can establish eco-friendly digital procurement by sharing data with suppliers via digital channels, bringing unique, precise, and trustworthy data regarding the suppliers, and outlining how they integrate green practices into their SC (Narayanamurthy and Tortorella, 2021). Further, digital technologies function as the core of environment safety operations and provide a broad framework for directing GIO behaviour for all participants throughout FSC (El-Gayar and Fritz, 2006). Technological innovations simplify the integration and coordination needs of eco-product design, manufacturing, packaging, and distribution with suppliers and consumers (Liu et al., 2018). Greenhouse gas emissions may be decreased and hygienic, eco-friendly packaging materials can be developed with the use of blockchain, AI, and IoT (Bradu et al., 2022; Ren et al., 2022). Food safety is enhanced by an effective and hygienic packing layout, which lowers wastage and greenhouse gas emissions (Wandosell et al., 2021).

According to OIPT, digital technologies enable businesses to better handle data, which helps organizations manage the higher degree of complexities and uncertainties inherent with GIO without investing in additional expenditures (Qu and Liu, 2022). Therefore, the presence of advanced digital technology will increase the effects of suppliers’ integration and consumer awareness on the advancement of green products and processes. Thus, the effectiveness of cooperation in enhancing GIO may be facilitated by integrating the well-built innovative skills of different stakeholders (Junaid et al., 2022). Thus, a hypothesis may be proposed as:

***H2:*** *Digital technologies have a positive impact on food supply chain green innovation.*

Green suppliers could promote the utilization of sustainable products across the FSC. For example, environmentally conscious consumers can also request new eco-friendly or reprocessed items to reduce their carbon footprints (Abbey et al., 2015). Such demands from the partners may encourage the advancement of new green practices (Zhu et al., 2013). Further, FSC participants may cooperate to advance recycling technology, establish better green strategies for product design, and optimize individual recycling procedures (Rahmani et al., 2021). Utilizing internal integration tactics, organizations may use an appropriate environmental management strategy to stabilize the relationship between their environmental innovation and profits (Wong et al., 2020; Aisjah and Prabandari, 2021). Using processes of integration including goal alliances, sharing of knowledge, integrative leadership networks, and structure, GIT may promote green innovation. GIT integrates commercial and ecological governance techniques to make investments in green innovation by elucidating the tactical decisions made by the Indian food sectors (Chi, 2022).

According to OIPT, it is challenging for an organization to analyze a large number of consumer data efficiently and to reduce uncertainty throughout its GI if it has a restricted information capability (Qu and Liu, 2022). Therefore, to eliminate asymmetric information and lessen the load of information processing, an organization must interconnect with its consumers and suppliers to maximize its information-processing capabilities (Enrique et al., 2022). Thus, a hypothesis may be proposed as:

***H3:*** *Food supply chain green integration positively impacts the food supply chain green innovation.*

Organizations may achieve sustainability via GSC integration by achieving their economic and environmental objectives (Das, 2018). To attain their performance goals, firms’ aims constantly concentrate on getting their consumers and suppliers to be green and use green operations (Heras-Saizarbitoria et al., 2011). Recently, there has been a lot of focus on the concept of SCGI and the way it relates to performance (Bon, 2018). Sustainable performance is the consequence of firm strategic capabilities, such as the SCGI (Fatoki, 2019). In order to lower costs and the influence on the ecosystem, GIT aligns green innovation in the food supply chain system (Chi, 2022). Furthermore, GIT achieves green product and process innovation and sets collaborative sustainable objectives and initiatives with food industry vendors and consumers (Chi, 2022).

To describe a firm's interactions with its providers and consumers and improve its information capacities, OIPT provides important insights into inter-firm configuration throughout FSCM (Enrique et al., 2022). According to OIPT, a firm's data effectiveness and capacity may be enhanced through the vertical and lateral integration of external information processing units (such as suppliers and customers) (Qu and Liu, 2022). Furthermore, the value of SCGI in enhancing performance has been established in research (Zhao et al., 2008; Narayanan et al., 2011; Zhu and Sarkis, 2016). SCGI can make independent contributions to environmental performance (Hsu et al., 2016; Laari et al., 2016). Thus, according to OIPT, an organization’s information-processing capability and performance may be enhanced through the horizontal or vertical integration of external information networks (e.g. suppliers and consumers) (Enrique et al., 2022). Thus, a hypothesis is proposed as:

***H4:*** *Food supply chain green integration has a positive impact on the sustainable performance of food supply chains.*

GIO increases environmental outcomes and is connected to a sustainable corporate strategy (Adegbile et al., 2017). GIO investments enable organizations to reduce manufacturing wastage and improve environmental performance (Singh et al., 2020). According to previous studies (de Burgos-Jim'enez et al., 2013; Lin et al., 2013), GIO must not be seen as a firm's responsive approach to community demands but rather as a strategy to enhance environmental outcomes to obtain competitiveness. GIO also enables organizations to adhere to environmental regulations, avoiding penalties and regulatory objections to the firms’ practices (Chen, 2008; Chang, 2011). Therefore, GIO favours an organization’s performance (Singh et al., 2022). Through waste reduction and improved operations effectiveness, GIO may assist the food industry become more productive (Huang and Li, 2017). According to Sunila et al. (2018), reducing pollutants to comply with food manufacturing regulations would also improve financial results.

Reducing costs and waste lessens the negative environmental impact of food firms’ operations and improves the corporation's economic success (Weng et al., 2015). According to research (Przychodzen and Przychodzen, 2015; Singh et al., 2020), investing in GIO may have positive effects on the economy. Also, it can boost a firm’s efficiency, revenue, consumer loyalty, capital returns, and economic success (Lin et al., 2013). According to OIPT, GIO practices improve technical procedures that strengthen enterprises' environmental, economic, and social performance by minimizing uncertainty (Burki et al., 2019). Thus, the hypothesis may be proposed as:

***H5:*** *Food supply chain green innovation has a positive impact on the sustainable performance of food supply chains.*

Based on the above research propositions formulated, Figure 1 represents the conceptual model among, digital innovative technologies, green innovation, green integration and food supply chain sustainable performance.

Base and Front-end Digital Technologies

FSC Green Integration

Strategic alignment for information-processing fit

Digital FSC Strategy

FSC Sustainable Performance

Organization information-processing fit

Information processing capability

FSC Green Innovation

Information boundary condition (SC Integration)

Information processing needs for innovative operation

|  |  |  |
| --- | --- | --- |
|  | H1  H3  H2 | H5  H4 |

**Figure 1:** Interlinking of Proposed theory (OIPT) and hypothesis formulation (Proposed conceptual framework)

**3. Research methodology**

**3.1 Questionnaire measures and data collection**

The specifics of the items used to define the various constructs are adapted from the past literature and provided in Appendix 1. 5-point Likert scales were used to evaluate each indicator. For pre-testing, a small group of area experts were selected from industry and academia for the content validation of the questionnaire. As per the given suggestions, some adjustments in terms of the phrasing of some items to make them applicable to India's standards.

The research team used a questionnaire survey to gather information aiming to test our hypothesis. We targeted large companies for collecting data because of their typically stand to gain better from sustainable initiatives than smaller ones as they typically capture greater consumer interest (Dixon–Fowler et al., 2012). Consequently, in order to capitalise on and improve their image, large businesses are more inclined to expand their use of green technology. Larger businesses may also afford to invest heavily in green technologies and take advantage of their green processes because they often have greater resources than smaller businesses (Qu and Liu, 2022). At the beginning of the data-gathering process, the research team contacted the individuals in their network and identified key contacts and participants that belonged to the various departments, such as purchasing, production, research and development, and logistics across different food industries spanning from young establishments (less than 10 years) to mature enterprises (more than 20 years). The team then used initial contacted networks to access more initial participants by asking them to refer others from their networks who might fit our inclusion criteria with a snowball effect to access a larger sample of data sources. In the data collection participation, an equal chance has given to ensure representative selection across different departments. This was done by randomly selecting a participant from each food industry in order to avoid selection bias to conduct an appropriate analysis of the relationship dynamics within each department. From total of 550 sent questionnaires, we have considered 268 relevant questionnaires with the response rate of 48.72%.

In order to confirm the reliability of the sample, we subjected it to a variety of tests. To begin, we used G\*power software to do a pre-test statistical power analysis (Cohen, 1988) with a medium effect size (0.15), a statistical power level of 0.95, three predictors, and a confidence level of 0.01. Based on the power study results, we know that a sample of at least 119 companies is necessary for our proposed framework. Since we have data from 268 different companies, we can confidently say that our sample is legitimate and statistically powerful enough to find meaningful differences (Cohen, 1988). In addition, there were less than 3% omissions per item in the obtained data, making it suitable for partial least squares (PLS) analysis (Hair et al., 2017). Figure 2 represents the research framework of the present research.

PLS, which is a variance-based structural equation modelling (SEM) was chosen to assess the theoretical framework since it is more resilient to non-normal distributions than covariance-based SEM (Leong et al., 2019). To do this, we used Smart PLS 4.0 to verify the statistical model's assumptions (Ringle et al., 2015). We performed further analyses using artificial neural networks (ANN) to rank the normalised relevance of the important predictors depending on the PLS analysis since there was evidence of nonlinear interactions among the predictor and outcome variables. Since the SEM-PLS is appropriate to investigate the hypothesis of linear associations but is unable to adequately represent the nonlinearity of interactions, the deployment of a two-staged PLS-ANN technique would support each other.   
The "black box" nature of the ANN makes it inappropriate for hypothesis evaluation, even if it is capable of detecting nonlinear correlations (Hew et al., 2016). Non-normal data distribution and the presence of non-linear correlations between the exogenous and endogenous variables are two reasons why the ANN should be used. Furthermore, the ANN exhibits robustness over small sample sizes, noise, and outliers. Additionally, it can support non-compensatory scenarios, in which an upsurge in one element does not necessarily require to offset a reduction in another. IBM's SPSS neural network module was used to carry out the ANN analysis. According to Teo et al. (2015), the ANN method does not require a normal distribution in order to detect both linear and nonlinear interactions.

* Extensive literature review and pre-testing of the questionnaire
* Development of structured questionnaire
* Scale: 5-point Likert scale

Instrument Deveopment

* **Sample Size:** 268; **Frame:** Indian food industries
* **Response Rate:** 48.72 %
* **Data Collection Period:** November 2022-April 2023

Sample & Data Collection

* Descriptive Statistics and Correlation (SPSS)
* **Measurement and Structural Model:** PLS-SEM (Smart PLS)
* **Hypothesis Testing:** PLS-SEM (Smart PLS)
* **Non- linear Relationship Testing:** Artificial Neural Network (SPSS)

Data Analysis

Da

**Figure 2:** Flowchart of research materials and methods

**3.2 Common method bias (CMB)**

The generation of common method bias (CMB) problems in survey-based research is caused by collecting perceptive data from a singular source at a particular moment in time (MacKenzie and Podsakoff, 2012). Researchers have adopted MacKenzie and Podsakoff (2012) and Podsakoff et al. (2003) recommendations for reducing the influence of CMB on the data-gathering process. As a result, we collected data from the selected respondents, utilized metrics from various research, secured the confidentiality of respondents, mitigated the item sequence for constructs to prevent a stimulatory effect and implemented a concise and simple measurement scale for the items. In addition, a complete collinearity test was performed to reduce the CMB influence. This was done following the method described by Kock (2017), which involves determining the variance inflation factor (VIF) value for each of the model's components. The findings of the PLS fit analysis show that none of the VIF values is higher than the threshold value of 3.3 (see Table 2) (Kock, 2017), which provides evidence that CMB was not a significant obstacle for this investigation.

**4. Results**

**4.1 Measurement model assessment**

The developing method of Confirmatory Composite Analysis (CCA) was used to evaluate the PLS-SEM measurement model (Hair et al., 2020). In recent years, CCA has emerged as the preferred method for analyzing “composite” measurement methods in PLS-SEM. The primary statistical purpose of CCA is to maximize variance recovered from independent variables, which sets it apart from the more prevalent Confirmatory Factor Analysis (CFA). As a result, it's easier to foresee how internal structures will behave (Hair et al., 2020). The PLS-SEM analysis followed the criteria proposed by Hair et al. (2017), and the findings were progressively reported. “Internal consistency, composite reliability, convergent validity, indicator reliability, and discriminant validity” should all be assessed since the measurement model is reflective. Cronbach's alpha (*α*) was used to determine internal consistency, and Dijkstra–Henseler's (*ρA*) was used to determine composite reliability in line with the aforementioned (Hair et al., 2017). Table 2 reveals *α*, *ρA*, and composite reliability values that are all higher than the recommended 0.7 cut-offs, suggesting stable, trustworthy results. Factor loadings and the Average variance extracted (AVE) criteria were used to evaluate convergent validity. All AVE values in this scenario were more than 0.5, demonstrating convergent validity (see Table 2). A factor loading larger than 0.5 is preferred for dependability indicators (Benitez et al., 2020). Table 2 shows that all indicators were over the 0.5 criteria and statistically significant at the 0.01 level, demonstrating that the measurements are credible.

**Table 2:** Construct reliability and validity measures

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Constructs** | **Item code** | **Loadings** | **VIF** | ***α*** | ***ρA*** | **CR** | **AVE** |
| Base and Front-end Digital Technologies  (BFEDT) | BFEDT1 | 0.833 | 2.153 | 0.896 | 0.899 | 0.923 | 0.706 |
| BFEDT2 | 0.838 | 2.278 |  |  |  |  |
| BFEDT3 | 0.827 | 2.247 |  |  |  |  |
| BFEDT4 | 0.853 | 2.328 |  |  |  |  |
| BFEDT5 | 0.849 | 2.341 |  |  |  |  |
| FSC Green Integration  (FSCGI) | FSCGI1 | 0.822 | 1.835 | 0.870 | 0.871 | 0.906 | 0.659 |
| FSCGI2 | 0.820 | 1.836 |  |  |  |  |
| FSCGI3 | 0.814 | 1.829 |  |  |  |  |
| FSCGI4 | 0.812 | 1.839 |  |  |  |  |
| FSC Green Innovation  (FSCGIO) | FSCGIO1 | 0.811 | 1.941 | 0.834 | 0.835 | 0.889 | 0.667 |
| FSCGIO2 | 0.806 | 1.973 |  |  |  |  |
| FSCGIO3 | 0.809 | 1.955 |  |  |  |  |
| FSCGIO4 | 0.820 | 1.997 |  |  |  |  |
| FSCGIO5 | 0.811 | 1.946 |  |  |  |  |
| FSC Sustainable Performance  (FSCSP) | FSCSP1 | 0.882 | 2.614 | 0.894 | 0.896 | 0.927 | 0.759 |
| FSCSP2 | 0.839 | 2.099 |  |  |  |  |
| FSCSP3 | 0.889 | 2.652 |  |  |  |  |
| FSCSP4 | 0.874 | 2.490 |  |  |  |  |

In this investigation, the heterotrait-monotrait ratio, also known as HTMT (Henseler et al., 2015), was used to evaluate the discriminant validity of the assessments (Hair et al., 2017). When assessing the discriminant validity of a model, the golden rule is that the HTMT value for each of the constructs in the framework should be less than “0.85 (using the conservative method) or 0.90 (using the liberal approach)” (Benitez et al., 2020). The values of HTMT for the variables are lower than 0.85, which is evident proof of the reliability and validity of the construct.

**4.2 Structural model assessment**

The first thing that had to be done while assessing the structural model was to check to see if there were any collinearity issues. This was done by looking at the Variance Inflation Factors (VIF) in each set of latent constructs included in the structural model (Hair et al., 2020). Table 2 shows that none of the VIF values is higher than 3.3, implying no collinearity issue with the model (Benitez et al., 2020; Hair et al., 2020). To test the hypothesis about the structural model, the bootstrapping method was used, and 5000 subsamples were utilized (there were no sign alterations) (see Figure 3 and Table 3). A confidence interval with a 95% level of accuracy was used to get both the beta coefficient (*β*) and the significance values. According to the findings, BFEDT has a strong impact, both positively and significantly, on FSCGI and FSCGIO. Additionally, FSCGIO and FSCGI have a substantial positive influence on FSCSP. Finally, FSCGIO is significantly impacted favourably by FSCGI. As a result, hypotheses H1, H2, H3, H4, and H5 were validated.

**Table 3:** Bootstrapping outcomes

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Path** | ***Β*** | **SD** | ***T* statistics** | ***P* values** | **Hypotheses**  **Decision** |
| BFEDT → FSCGIO | 0.287 | 0.074 | 3.852 | 0.000 | Accepted |
| BFEDT → FSCGI | 0.640 | 0.053 | 11.994 | 0.000 | Accepted |
| FSCGIO → FSCSP | 0.313 | 0.065 | 4.787 | 0.000 | Accepted |
| FSCGI → FSCGIO | 0.450 | 0.084 | 5.383 | 0.000 | Accepted |
| FSCGI → FSCSP | 0.395 | 0.063 | 6.280 | 0.000 | Accepted |

*β* = 0.287,

*t = 3.852*

*β* = 0.313,

*t = 4.787*

Base and Front-end Digital Technologies

FSC Green Innovation

FSC Sustainable Performance

FSC Green Integration

*β* = 0.450,

*t = 5.383*

*β* = 0.640,

*t = 11.994*

*β* = 0.395,

*t = 6.280*

**Figure 3:** Final resultant model

Furthermore, *R2*, *f2*, and *Q2* were used to assess the structural model's usefulness for making predictions (Benitez et al., 2020; Hair et al., 2020). The findings of the analysis show that after taking into account the number of predictors, FSCGIO (0.450), FSCGI (0.409), and FSCSP (0.411) have respectable levels of *R2*. We also tested the model's predictive accuracy using the *Q2* Stone-Geisser. Henseler et al. (2009) suggest a *Q2* larger than zero for the concept to be considered significant as an excellent predictor. The findings demonstrate that the *Q2* values derived from blind testing are non-zero, suggesting that the framework has a predictive ability. Further, outcomes indicate the effect size of all the predictor variables, varying from small (0.088) to large (0.693) variances in different constructs. Finally, the values of SRMR (0.053< 0.201), d\_ULS (0.477< 13.127), and d\_G (0.229 < 6.602), all of which are optimal, show that the proposed framework is a good fit (Benitez et al., 2018).

**4.3 Testing hypothesis robustness using Artificial Neural Network (ANN) analysis**

PLS-SEM and ANN were coupled to highlight the non-linear association between the variables due to the limited ability of PLS-SEM to test for linear relationships, which suggests it might not be the best choice for more nuanced decisions (Theadora et al., 2022). ANN is a "large processor made up of neurons, which are basic processing units that may store information for usage in the future" (Ooi et al., 2018). As part of this research, three ANN models were developed to predict BFEDT, FSCGI, FSCGIO, and FSCSP. Root mean squared error (RMSE) values are shown in Table 4, together with their respective means and standard deviations (SDs) for both the “training (learning) and testing (predicting)” phases. Predictions made by the ANN models are very accurate (see Table 4), with a mean RMSE of between 0.417 and 0.536 (considered minimal with insignificant SD in both the “learning and predicting” phases) (Lo et al., 2022).

**Table 4:** Root mean squared error scores for constructs

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **ANN model testing sequence** | **Model 1**  **Input variables:** FSCGI and FSCGIO  **Output variables:** FSCSP | | **Model 2**  **Input variables:** BFEDT and FSCGI  **Output variables:** FSCGIO | | **Model 3**  **Input variables:** BFEDT  **Output variables:** FSCGI | |
| Training RMSE | Testing RMSE | Training RMSE | Testing RMSE | Training RMSE | Testing RMSE |
| **1** | 0.520 | 0.274 | 0.494 | 0.485 | 0.505 | 0.542 |
| **2** | 0.538 | 0.213 | 0.466 | 0.641 | 0.524 | 0.490 |
| **3** | 0.522 | 0.440 | 0.511 | 0.450 | 0.539 | 0.516 |
| **4** | 0.535 | 0.515 | 0.499 | 0.245 | 0.547 | 0.532 |
| **5** | 0.525 | 0.485 | 0.493 | 0.302 | 0.535 | 0.438 |
| **6** | 0.521 | 0.517 | 0.506 | 0.426 | 0.518 | 0.680 |
| **7** | 0.583 | 0.573 | 0.489 | 0.386 | 0.520 | 0.691 |
| **8** | 0.526 | 0.518 | 0.459 | 0.515 | 0.517 | 0.359 |
| **9** | 0.550 | 0.593 | 0.474 | 0.235 | 0.535 | 0.419 |
| **10** | 0.545 | 0.291 | 0.475 | 0.483 | 0.534 | 0.599 |
| **Mean** | 0.536 | 0.442 | 0.486 | 0.417 | 0.527 | 0.527 |
| **Standard deviation** | 0.018 | 0.127 | 0.016 | 0.121 | 0.012 | 0.103 |

Table 5 displays the results of a sensitivity analysis used to compare the exogenous constructs in this study. According to ANN Model 1, FSCGI is the best predictor of FSCSP (100% normalized relative significance), followed by FSCGIO (71.50%). Further, according to ANN Model 2, FSCGI is the best predictor of FSCGIO (100% normalized relative relevance), with BFEDT coming in second (33.30%). Finally, there is just one neuron in ANN Model 3, and the sensitivity analysis predicts a value of 100% for normalized importance. In Table 5, we compare the path coefficient (from PLS-SEM bootstrapping) and normalized relative importance (from ANN independent variable important analysis) to see how PLS-SEM and ANN vary in their rankings. Models 1, 2, and 3 of the ANN agree with the rankings generated by the PLS-SEM models. This way, the results drawn from PLS-SEM and ANN are consistent for each association between different constructs.

**Table 5:** Result comparison between PLS-SEM and ANN

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **PLS path** | **Path coefficient** | **ANN: Normalized importance** | **Ranking determined by PLS-SEM** | **Ranking determined by ANN** | **Outcome (Consistent/ Inconsistent)** |
| **Model 1: Input variables:** FSCGI and FSCGIO; **Output variables:** FSCSP | | | | | |
| FSCGI → FSCSP | 0.395 | 100.00% | 1 | 1 | Consistent |
| FSCGIO → FSCSP | 0.313 | 71.50% | 2 | 2 |
| **Model 2: Input variables:** BFEDT and FSCGI; **Output variables:** FSCGIO | | | | | |
| FSCGI → FSCGIO | 0.450 | 100.00% | 1 | 1 | Consistent |
| BFEDT → FSCGIO | 0.287 | 33.30% | 2 | 2 |
| **Model 2: Input variables:** BFEDT; **Output variables:** FSCGI | | | | | |
| BFEDT → FSCGI | 0.640 | 100.00% | 1 | 1 | Consistent |

**5. Discussion and implications**

This research aims to understand the role of base technologies such as IoT, blockchain, and others, as well as end technologies such as collaborative robotic systems, 3D printing, and so on, in enhancing SCI's digitalization and information processing capabilities for information monitoring and collaboration in the face of sustainable development (Frank et al., 2019). Integrating base and front-end technologies can significantly improve a firm’s information-processing capabilities by offering an interface for simple data exchange and seamless connectivity systems between multiple operational elements within companies and between these and their distributors and clients (Enrique et al., 2022). DTs are at the core of environmental safety operations, providing a comprehensive framework for driving GIO behaviour for all FSC stakeholders (El-Gayar and Fritz, 2006). Furthermore, DTs enable companies to manage data better, managing the increased complexity and uncertainties associated with GIO without incurring extra costs (Qu and Liu, 2022).

We tested five hypotheses based on responses from 268 executives working in FSC-oriented sectors in India. The results support the first hypothesis, which suggests that a company may greatly simplify its integration of green suppliers and its green customers' emphasis via digital FSC through base and front-end technology (Enrique et al., 2022). In addition, augmented reality personnel may reorganize warehouses by showing them how to use more efficient layouts and designs (Rejeb et al., 2021; Dornelles et al., 2022). Although prior research and popular media have established the significance of back-end and front-end technologies to FSCGI (Enrique et al., 2022), very little evidence exists to back up claims about how digital technologies can be used to enhance FSCGI, making the current findings even more intriguing. As such, our results provide credence to the argument that DTs are crucial to FSC's GI.

Similarly, we found credence in our second hypothesis, which claims that using digital technology (both base and front-end) improves the FSCGI. Organizations may better handle the complexity and uncertainties associated with GI without incurring extra costs, according to OIPT, because of the improved data handling made possible by DT (Qu and Liu, 2022). Therefore, improved digital technology will boost the impact of integrated suppliers and knowledgeable consumers on creating environmentally friendly goods and services. Thus, the second hypothesis is consistent with the findings of Birkel and Müller, (2020), Kumar et al. (2021), and Narayanamurthy and Tortorella (2021).

Moreover, our results support the study's third hypothesis, which proposes that GI benefits FSCGIO. According to OIPT, it's difficult for a company to properly analyze a huge volume of customer data and minimize uncertainty across its GI if its information capabilities are limited (Qu and Liu, 2022). Therefore, a company must network with its customers and vendors to reduce the impact of asymmetric information and streamline its information-processing operations (Enrique et al., 2022). In this manner, the outcomes of the third hypothesis are aligned with prior findings by Aisjah and Prabandari (2021), Rahmani et al. (2021), Wong et al. (2020), and Zhu et al. (2013).

The study's fourth and fifth hypotheses, which look at how FSCGI and FSCGIO relate to FSCSP, are also supported. In order to improve an organization's information-processing capabilities and performance, OIPT suggests integrating external information networks (such as those of suppliers and customers) either horizontally or vertically (Enrique et al., 2022). The widespread one-on-one, small-group, and large-scale contacts facilitated by such an inter-organizational framework provide effective data processing and reduced levels of uncertainty (Galbraith, 1973; Egelhoff, 1991). As shown by earlier research, green supply chain integration is essential for improving performance. GI investments, for example, have been shown to increase a company's productivity, income, customer loyalty, capital returns, and overall economic performance (Lin et al., 2013). By reducing risk, green integration practises, as outlined by OIPT, boost the technical processes that boost any business's environmental, economic, and social outcomes (Burki et al., 2019). Accordingly, the results of the fourth hypothesis are consistent with those of prior research by Koufteros et al. (2007), Zhao et al. (2008), Narayanan et al. (2011), Zhu and Sarkis (2016). Previous research by Przychodzen and Przychodzen (2015) and Singh et al. (2020) all lend credence to the results of the fifth hypothesis (2020).

**6. Theoretical and practical implications**

**6.1 Theoretical implications**

Investigating the connection between DTs, FSCGI and FSCGIO, and FSCSP, in particular concerning the OIPT theory, was the primary purpose of the present study. The potential relationships between all of these constructs have been investigated in previous studies (Enrique et al., 2022; Kumar et al., 2021; Aisjah and Prabandari, 2021; Singh et al., 2020; Zhu and Sarkis, 2016), and those studies have either found them or indicated that they exist. On the other hand, each of these relationships is investigated or proposed separately and within a broad context; there is no theoretical basis for any of these investigations or proposals. Therefore, this is the first study that looks at the interaction between DTs, FSCGI and FSCGIO, and FSCSP as a unified endeavour via the lens of OIPT theory.

The development of a robust causal link between existing (DTs, FSCGI and FSCGIO) and defined (FSCSP) supply chain management philosophies is another contribution that this research provides to the current corpus of the OIPT theory. This conclusion has been incorporated into the body of research pertaining to the OIPT theory. The perspective could be taken to suggest that these four concepts (DTs, FSCGI and FSCGIO, and FSCSP) have the capacity to create the notion of an FSC enterprise if the firm is susceptible to the influence of the OIPT theory.

Thirdly, from the methodology perspective, the large number of individuals who participated in the study (*n* = 268) makes it possible to extrapolate the findings statistically (Chand et al., 2022). More specifically, the findings provide a quantitative evaluation of the association, revealing the degree to which the engagement impact exists. In this article, a theoretical contribution is made to the ongoing conversation about how FSC institutions might use DTs, FSCGI and FSCGIO, and FSCSP to comprehend the interface actions that lead to the production of outcome measures, with an increasing focus on the OIPT theory. Our findings shed insight into how FSC companies interact with DTs, FSCGI, FSCGIO, and FSCSP. In addition, the research findings offer a foundation for the conceptual justification of future research that is comparable to the one that is now being conducted. They do so within the framework of a separate sector of the economy.

The OIPT paradigm was developed by Shiffrin and Schneider (1977) to explain the intellectual learning process that humans go through to transform sensory material in a cognitive way. In later years, OIPT was used to manage the flexible organizational operations involved in learning (Grah et al., 2016). According to the study's discoveries, FSC businesses can acquire a competitive advantage by incorporating digital technologies, green integration, and innovation because of the optimistic and causally significant relationships among these variables. This promotes the expansion of sustainability-related facets within the FSC, especially by providing an interface for straightforward data interchanges and effortless interconnection structures between various functional components. This study suggests that these abilities may serve as the cornerstone for FSC companies' ability to offer a strategic advantage through sustainable performance and have theoretical repercussions.

**6.2 Social and managerial implications**

This research advances the sustainable development objectives outlined in the United Nations' 2030 roadmap for sustainable development. Our analysis aligns with Goal 12: Promote environmentally friendly methods of consumption and manufacturing, one of the 17 goals outlined in the 2030 agenda. The objective is to implement strategies that may assist in lowering the carbon and material footprint of corporations and, by extension, countries. Our research demonstrates that food industries can enhance multiple green outcomes measurements that support this objective by implementing digital technologies and green innovation in their supply chain. These indicators include recycled material, emission reduction, and resource consumption, which further include the utilisation of dangerous and environmentally damaging substances. Additionally, the current analysis suggests that the Indian food industry should increase its ability for information processing. By establishing secure relationships with consumers, businesses may lessen information asymmetries and lessen the strain associated with data handling. A firm that practices a high degree of client attention may connect and negotiate with its clients directly, preventing misunderstandings about their desires and interests in terms of their values. Also, the present research ensures food security and calls for a multipronged approach that includes social safety, supplying nutritious food, particularly for youths, and altering food SC networks to build a more just and sustainable society.

The findings of the present study have substantial implications for managers’ interpretation of the effect of DTs on GI and GIO, as well as the impact of GI and GIO on FSCSP and the impact of GI on GIO within the template of the OIPT theory. Professionals, executives, and decision-makers in FSC firms may be able to deliver more sustainable results, boost efficiency, and decrease costs by leveraging DT as an integrated strategy in the company. This will help firms remain productive in this constantly shifting environment. Moreover, these two factors give the exceptional perspective that GI and GIO have offered into each and every part of FSC.

For instance, Rai (2022), in his recent blog, discussed the impact of digitalization and innovation in the Indian agriculture sector. According to Rai (2022), future success will be marked by the widespread use of digital food grain and commodities storage trade systems and procedures incorporated with real-time surveillance of supply and demand powered by AI. The mandi (where the trade of raw materials happens in India) of the coming years will be a computerized storehouse, serving as the nerve centre of the market. Farmer's products are digitized, and a digital balance is created at the storage unit, where quality is evaluated, and financing is made available in near real-time. Farmer’s organizations could use this centre with digital channels to make important decisions, including whether or not to sell, when to sell, where to sell, and how to connect with service providers and advisors. Here, it is clear how information processing is crucial to achieving the results that improve the agricultural food supply chain.

According to the findings of this study, it is likely that in the not-too-distant future, FSC organizations worldwide, including those in India, will progressively embrace digital technology in harmony with green integration and innovation. Because FSCGI and FSCGIO have a direct favourable impact on FSCSP, practitioners consider them to be key motivating factors for acquiring FSCSP in their pertinent areas of expertise within the assumptions of the OIPT domain. This is illustrated by the fact that FSCGI and FSCGIO have a favourable direct impact on FSCSP. For example, the business has traditionally been complex, with various shifting components, but due to contemporary technology, things are getting simpler for both the people who make food and the people who consume it (Aeologic, 2022). Among the methods technology is helping to improve the FSC include using AI and mobile applications (Aeologic, 2022).

The policymakers could use the empirical findings to implement green integration and innovation initiatives to deliver a sustainable FSC. For instance, the “Green Innovation Centre India” recognizes and encourages the enormous opportunity that lies within agribusiness to provide food and health stability and to serve sustainable growth (Schoenberger and Berghoff, 2020). Additionally, green and digital technologies are progressively employed to avoid, recover, and reuse food scraps, throwing up new prospects for business and society. For instance, there are innovations and advancements in “thermal preservation, biological and biochemical preservation, cold photovoltaic stores, active packaging, waste-to-energy, composting, recycling, and upcycling” (UNEP, 2022). Furthermore, digital technologies such as the IoT and mobile applications enable innovative solutions for the distribution of food, smart tagging, price optimization, tracking, smart dispersal, and scheduling of purchasing and dining, as well as preservation (UNEP, 2022).

It would be beneficial for managers of FSC companies to recognize the significance of digital technologies, green integration, and green innovation as facilitators of FSCSP due to the positive influence of these attributes on FSCSP. The premises of the OIPT theory require that managers understand that digital technologies, green integration, and green innovation are the inspiration and basis for FSCSP projects, and managers should be aware of this.

**7. Conclusions, limitations, and future research**

The perspectives of working experts from Indian FSC companies integrating DTs, FSCGI and FSCGIO are utilized in this study. For this study, interviews were conducted with FSC industry professionals. The findings of the research are interpreted in light of the inferences of the study. They could serve as a point of reference for FSC organizations that are contemplating the use of DTs, GI, and GIO to obtain FSCSP-driven benefits within the context of the OIPT theory. Insights into how the OIPT theory might be incorporated into digital technologies, green integration, and green innovation, as well as FSCSP action plans, were also gained because of the analysis of the 268 responses received from FSC companies. As a result of the findings, which indicate that both environmentally friendly integration and environmentally friendly innovation contribute significantly to the enhancement of FSCSP, it is recommended that FSCSP businesses implement both forms of technology simultaneously. The current study offers a detailed investigation of how GIO, GI, and DTs impact the FSC organizations' ability to maintain sustainable performance. Some of the limitations of the previous research, as well as some suggestions for the future, are discussed further.

In the present research, these two ideas were broken apart so that researchers could investigate both the influence of DTs on GI and GIO and the influence of GI and GIO on FSCSP. When placed side by side, the techniques of GIO and GI utilize a variety of diverse technologies. However, it is vital to research GI and GIO's effect on FSCSP. The purpose of the present study, driven by the OIPT perspective, is to evaluate the influence of FSCGI and FSCGIO on the firms’ FSCSP. Despite this, there is still a chance that none of these methods will produce the same association when applied to a new setting. Future research could investigate the connection between FSCSP, GI, and GIO in various unrestricted situations. This research establishes no clear hierarchy among OIPT-related topics, including FSC, green integration and innovation, and digital technologies. Therefore, future research may want to look at various ranking methods for organizing the opinions of professionals on various innovations and actions into a hierarchy in line with the limitations of the OIPT theory. To boost enterprises’ green advancements, future research should focus on identifying the triggers or elements that might increase green vendor cooperation and green consumer engagement. Furthermore, this research only included statistics from the Indian food sector; other heavily polluting corporations, such as the service sector, also have significant environmental issues and engage in environmentally friendly practices. In order to improve the generality of the findings, future studies might include the service industries and increase the sample size. Lastly, we did not distinguish across various forms of green innovation in our research. It is apparent that several forms of green innovation may have varying relationships with the long-term sustainability of the food industry, and that these relationships may be mediated by distinct pathways. As a result, future scholars must segregate various forms of green innovation.

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