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RESEARCH PAPER

Technological adoption in green practices as a mediator between green supply chain practices and operational performance: evidence from the agro-processing and food industry

Md Mehedi Hasan Emon[1], Mowdud Ahmed[2]

[1]American International University-Bangladesh (AIUB), Bangladesh.
[2]Westcliff University (WU), Irvine, USA.

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ABSTRACT

Purpose: This study investigates the mediating role of Technological Adoption in Green Practices (TAGP) in strengthening the relationship between Green Supply Chain Management (GSCM) practices, Green Procurement (GP), Eco-Friendly Packaging (EFP), Waste Management Efficiency (WME), and Supplier Environmental Collaboration (SEC) and Operational Performance (OP) in Bangladesh's agro-processing and food industry. It aims to identify how technology integration enhances the effectiveness of sustainable practices and overall operational efficiency.

Design/methodology/approach: A quantitative research approach was employed, collecting data through structured questionnaires distributed to 325 agro-processing firms in Bangladesh. After screening, 243 valid responses were analyzed using SmartPLS for Partial Least Squares Structural Equation Modeling (PLS-SEM). This method allowed for the evaluation of both measurement and structural models, assessing direct and mediated relationships among GSCM practices, TAGP, and OP.

Findings: EFP and SEC had significant positive effects on OP. Technological Adoption in Green Practices also demonstrated a significant direct influence on OP. Mediation analysis confirmed TAGP as a significant mediator in all four green practices performance relationships, revealing that technology integration is vital to transforming green initiatives into measurable operational outcomes.

Practical implications: The study offers valuable insights for managers and policymakers, emphasizing the necessity of technological investment to optimize green initiatives and improve performance within the agro-processing sector.

Social implications: Promoting sustainable and tech-enabled practices can contribute to environmental conservation and resource efficiency, benefiting both society and the economy.

Originality/value: This study uniquely integrates TOE, RBV, and NRBV frameworks to empirically demonstrate the pivotal role of technology in enhancing green supply chain performance in a developing country context.

Keywords: Green Supply Chain; Technological Adoption; Operational Performance; Agro-Processing; Bangladesh; Sustainability; SmartPLS; TOE Framework.

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1 INTRODUCTION

The significance of sustainability in the global corporate landscape has escalated swiftly, compelling enterprises to implement eco-friendly strategies to reduce their environmental footprint. The agro-processing and food sector, which is integral to the economy of Bangladesh, is no exception. Green supply chain practices (GSCP) are essential for boosting environmental sustainability, minimizing costs, and improving operational performance (OP). Nonetheless, despite the increasing recognition of sustainable practices, their execution continues to pose difficulties, especially in developing nations such as Bangladesh. This study examines the mediating effect of technological adoption on the link between GSCP and OP in Bangladesh's agro-processing and food sector.

The agro-processing and food sector in Bangladesh is crucial to the national economy, significantly contributing to employment, food security, and export earnings. The sector has undergone substantial growth recently, propelled by the nation's agricultural foundation, which yields a diverse range of raw materials, and the increasing global demand for processed food (Fardet & Rock, 2020). Bangladesh is among the world's foremost producers of crops such as rice, jute, and diverse fruits, hence bolstering its dynamic agro-processing sector. The increasing demand for processed food products has rendered the sector's environmental effect a significant problem. The agro-processing sector in Bangladesh is characterized by significant resource utilization, waste production, and environmental deterioration, raising apprehensions regarding the long-term viability of these practices (Kibret *et al.*, 2023). In light of these challenges, there is an increasing emphasis on implementing Green Supply Chain Management (GSCM) practices, which seek to mitigate the environmental impact of supply chains by incorporating sustainable practices at every phase, from sourcing and production to waste disposal (Ali *et al.*, 2020; Emon, 2025b). GSCM includes several environmentally sustainable strategies such as eco-design, waste minimization, energy efficiency, sustainable procurement, and recycling (Bashar *et al.*, 2023). By integrating these techniques into their operations, organizations can diminish their carbon footprint while simultaneously improving operational efficiency and addressing increasing customer and regulatory demands for sustainability. The implementation of GSCM methods can substantially enhance environmental sustainability and operational efficiency in Bangladesh's agro-processing industry. The adoption of these methods is sluggish, mainly due to technological limits, budgetary constraints, and regulatory obstacles. Numerous companies in the industry persist in utilizing antiquated manufacturing methods and lack the technological framework necessary for the efficient implementation of sustainable practices. Energy-efficient technology and waste-to-energy solutions remain underutilized in the agro-processing sector, constraining the industry's capacity to minimize waste and enhance resource efficiency (Das & Mahalik, 2023). Moreover, although GSCP can enhance environmental performance, they necessitate substantial investments in technology, which many firms in Bangladesh's agro-processing sector are unable to afford due to financial limitations and restricted access to green technologies (Rasul & Gurung, 2024). The deficiency of technological infrastructure, coupled with insufficient support from both governmental and corporate entities, constitutes a substantial obstacle to the extensive implementation of sustainable practices. The regulatory framework for advancing green practices in Bangladesh's agro-processing sector remains nascent, hence impeding their implementation (Hira *et al.*, 2022). Nonetheless, the integration of technology into sustainable practices, including energy-efficient systems, renewable energy solutions, and sophisticated recycling technologies, might assist companies in surmounting these obstacles. By incorporating these technologies, agro-processing companies can diminish their environmental footprint while simultaneously boosting operational efficiency through optimized energy consumption, waste reduction, and improved supply chain effectiveness (Huang & Mao, 2024). The use of these green technologies could significantly contribute to the shift towards more sustainable and efficient agro-processing methods in Bangladesh, thereby positioning the industry for enduring growth and resilience against environmental issues.

The agro-processing and food business in Bangladesh is presently undergoing a gradual but significant transition towards the implementation of GSCM methods. This transformation is mostly propelled by governmental initiatives and global pressures, which compel companies to incorporate more sustainable practices into their operations. The Bangladeshi government has acknowledged the significance of sustainability across multiple sectors, including agro-processing, and has implemented different laws to encourage environmentally friendly practices, such as incentives for energy efficiency and waste reduction (Namagembe, 2021). International organizations and worldwide consumers are advocating for enhanced sustainable sourcing and production techniques, hence prompting enterprises in the agro-processing sector to implement environmentally friendly procedures to satisfy these expectations. Nonetheless, despite these

initiatives, the implementation of green supply chain techniques in the agro-processing sector progresses sluggishly, chiefly due to substantial physical obstacles and insufficient technological assistance. Numerous companies continue to depend on conventional production techniques that are resource-intensive and detrimental to the environment. For example, although certain companies have initiated waste management systems and procured sustainable raw materials, the adoption of more sophisticated green technologies, including energy-efficient production systems, renewable energy solutions, and closed-loop recycling processes, remains limited (Hagelüken & Goldmann, 2022). This technological disparity considerably restricts the complete realization of sustainable practices, preventing numerous companies from attaining the intended ecological and operational results. Furthermore, the financial limitations encountered by numerous agro-processing enterprises in Bangladesh impede their capacity to engage in essential green technology (Mujeri & Mujeri, 2021). The budgetary constraints are exacerbated by the absence of a robust infrastructure that facilitates the implementation of these technologies. The legislative system for green practices in Bangladesh remains immature, lacking robust enforcement measures to ensure adherence to environmental norms (Lie & Alam, 2025). In light of these problems, comprehending the significance of technology in facilitating sustainable supply chain practices is essential. Technological adoption can reconcile sustainable practices with OP by promoting resource efficiency, minimizing waste, and improving overall supply chain sustainability (Khan *et al.*, 2022). The agro-processing and food business in Bangladesh is experiencing heightened pressure to implement sustainable practices due to escalating environmental concerns and external demands for more Eco-Friendly Packaging (EFP) methods. GSCM strategies, including green procurement (GP), sustainable packaging, Waste Management Efficiency (WME), and engagement with environmentally conscious suppliers, are essential for improving sustainability in this industry (Le *et al.*, 2022). Nonetheless, despite acknowledging these practices, the implementation of green practices in the agro-processing sector progresses slowly and frequently proves unsuccessful, mostly due to inadequate technological infrastructure and restricted technology acceptance. Technological adoption in green practices (TAGP) considerably enhances the efficacy of GSCM by enhancing resource efficiency, minimizing waste, and optimizing industrial processes (Yadav *et al.*, 2024). However, the intermediary function of technological adoption in the correlation between GSCP and OP is still inadequately investigated, particularly within the framework of Bangladesh's agro-processing sector. Prior research has indicated that although companies may adopt fundamental green practices like waste management and sustainable packaging, the absence of advanced technologies, including energy-efficient systems and waste-to-energy solutions, constrains the complete efficacy of these initiatives (Khawaja *et al.*, 2024). Furthermore, there exists a deficiency in comprehending how the implementation of technology in sustainable practices might influence the effects of GP, environmentally friendly packaging, WME, and Supplier Environmental Collaboration (SEC) on OP. While these environmentally friendly methods are deemed crucial for enhancing operational efficiency and sustainability, their true effect on OP is frequently obstructed by technological impediments (Al-Emran & Griffy-Brown, 2023). Consequently, agro-processing enterprises in Bangladesh are unable to fully capitalize on the advantages of green supply chain techniques, leading to unsatisfactory OP.

The primary objective of this study is to explore the mediating role of TAGP in enhancing the relationship between GSCP namely, GP, EFP, WME, and SEC and OP in the agro-processing and food industry of Bangladesh. Specifically, the study aims to examine how the adoption of advanced technologies in green practices can facilitate the successful implementation of these GSCP, thereby improving operational efficiency, reducing environmental impact, and enhancing overall performance within the sector. By addressing this gap, the study will provide insights into how agro-processing firms in Bangladesh can leverage technological advancements to optimize their green practices and improve both environmental and operational outcomes.

This study provides a novel contribution to the literature on GSCM by examining the mediating function of TAGP within Bangladesh's agro-processing and food sector. Although prior research has thoroughly investigated the direct correlation between GSCP and OP, limited studies have addressed how technological adoption can augment the efficacy of these practices, especially in emerging economies such as Bangladesh. This research addresses a significant gap by examining how technological infrastructure, including energy-efficient systems and waste-to-energy technologies, can enable the effective execution of green practices such as GP, EFP, WME, and supplier environmental collaboration, thus enhancing OP. Moreover, the agro-processing sector in Bangladesh faces distinct hurdles, such as restricted access to modern technologies, financial limitations, and insufficient regulatory backing, hence amplifying the importance of technological adoption. This study's originality resides in its emphasis on comprehending how to surmount technology obstacles to enhance GSCP within a developing nation framework. This research analyzes the relationship between technological adoption and GSCP, offering a thorough understanding of how enterprises in Bangladesh might reconcile sustainability objectives with OP.

The study highlights the mediating function of TAGP, so enhancing existing research by providing a more refined perspective on how technology might facilitate the effectiveness of green supply chain activities in promoting operational efficiency and environmental sustainability. This research offers significant insights for both academia and industry professionals, including practical recommendations for policymaking, technology implementation, and operational strategies within the agro-processing sector.

2. THEORETICAL FRAMEWORK AND HYPOTHESIS DEVELOPMENT

This study's theoretical framework is based on three key theories: the Technology-Organization-Environment (TOE) Framework, the Resource-Based View (RBV), and the Natural Resource-Based View (NRBV). Each theory offers significant insights into the mediating role of TAGP and its influence on the relationship between GSCP and OP in the agro-processing sector. The TOE framework is a prevalent approach for analyzing the determinants of technology adoption in companies. The paradigm asserts that the adoption of new technologies is influenced by three primary contexts: technological, organizational, and environmental (Khan *et al.*, 2025). The technological context pertains to the accessibility and suitability of technologies, the organizational context concerns the internal attributes of the firm (including resources, processes, and culture), and the environmental context relates to external influences such as market pressures, competition, and regulatory conditions (Chen & Liang, 2023). The TOE framework is essential in substantiating the mediating function of TAGP within this study. By embracing green technologies, agro-processing companies can overcome the technological obstacles that impede the comprehensive execution of GSCP, including GP, EFP, WME, and SEC. The technological context emphasizes that innovations such as energy-efficient systems, waste-to-energy solutions, and eco-design technologies facilitate the effective implementation of these sustainable practices. The organizational environment elucidates how a firm's internal strengths, including leadership, resources, and creativity, can promote or obstruct the adoption of these technologies. Finally, the environmental context highlights external constraints from regulatory frameworks, consumer demands, and global sustainability trends that compel enterprises to adopt more sustainable practices. The TOE framework offers a thorough perspective on how the interaction of technological, organizational, and environmental factors affects the adoption of green supply chain techniques and their influence on OP.

The RBV thesis posits that organizations can attain a competitive advantage through the exploitation of distinctive internal resources and skills. In this perspective, resources are valuable, scarce, inimitable, and non-substitutable assets that enhance sustained performance (Baia *et al.*, 2020). The RBV supports the idea that GSCP, including GP, EFP, WME, and SEC, can function as useful resources for enhancing OP. These techniques allow organizations to maximize resource utilization, minimize waste, and bolster sustainability, so enhancing both efficiency and competitiveness. TAGP, analyzed via the framework of RBV, is seen as a strategic asset that facilitates enhanced performance. The use of green technologies is seen as an essential competency that facilitates the execution of sustainable practices and bolsters a firm's enduring competitive advantage (Emon & Khan, 2025b). By implementing modern technology for waste management or sustainable packaging, companies can enhance their environmental impact while simultaneously realizing operational cost reductions, hence enhancing overall performance (Hegab *et al.*, 2023). This strategic asset enables companies to distinguish themselves in the marketplace by providing environmentally sustainable products and services, which are progressively sought after by consumers and stakeholders.

The NRBV enhances the RBV by concentrating on the significance of environmental sustainability in achieving competitive advantage. While the RBV underscores the significance of internal resources, the NRBV posits that sustainable behaviors and environmental resources, such as green technologies, are essential for enduring success (Hamdoun, 2020). NRBV posits that companies should pursue economic benefits via effective resource utilization while simultaneously minimizing adverse environmental effects in their activities. This study posits that the NRBV substantiates the notion that GSCP, bolstered by technological implementation, can improve OP by incorporating environmental sustainability into the firm's fundamental operations. By implementing ecologically sustainable technology like waste-to-energy systems or renewable energy solutions, companies in the agro-processing industry can enhance operational efficiency while also aiding in environmental conservation. NRBV asserts that these green technologies are not simply compliance instruments but essential assets that can yield enhanced performance results (Trần *et al.*, 2025). In this context, NRBV offers a theoretical framework for comprehending how environmentally responsible practices, bolstered by technological innovation, are crucial for improving OP and attaining a sustainable competitive advantage. Collectively, these three theories—TOE, RBV, and NRBV—provide a comprehensive theoretical framework for analyzing the

correlation between GSCP, technological uptake, and operational success. They emphasize the diverse aspects that affect the adoption of sustainable practices and the significance of technology innovation in surmounting obstacles and augmenting the efficacy of these practices in enhancing operational results. This theoretical framework offers a thorough foundation for examining the mediating function of TAGP within the agro-processing sector in Bangladesh.

2.1 Hypotheses Development

GP denotes the acquisition of goods and services that exhibit diminished environmental effect across their entire life cycle, from manufacture to disposal. This notion has garnered considerable attention in supply chain management as an essential component of green supply chain strategies, especially in industries pursuing sustainability (Bag *et al.*, 2021). GP prioritizes the procurement of eco-friendly materials, mandates supplier adherence to sustainability criteria, and seeks to minimize resource consumption, hence diminishing environmental impacts (Badhwar *et al.*, 2024). In the agro-processing sector, GP encompasses the acquisition of environmentally sustainable raw materials, energy-efficient equipment, and EFP, all essential for minimizing waste and improving operating efficiency. The influence of GP on OP is extensively recorded in the current literature. Companies that implement GP techniques frequently achieve superior OP via resource optimization, cost savings, and greater supply chain efficiency. Eco-friendly procurement can result in diminished energy use, less waste production, and enhanced adherence to environmental rules, all of which facilitate cost savings and operational enhancements (Opoku, 2025). These practices enable organizations to bolster their sustainable credentials, so enhancing their reputation and market competitiveness, which can subsequently result in increased customer loyalty and improved operational efficiency (Rastogi *et al.*, 2024). Moreover, using GP methods can enhance supply chain efficiency by mitigating environmental risks and promoting collaboration with eco-conscious suppliers. This partnership frequently leads to the creation of more effective production processes, punctual deliveries, and the capacity to achieve sustainability objectives, all of which immediately improve OP (Ramanathan *et al.*, 2021). Agro-processing enterprises in Bangladesh can enhance their overall performance by applying GP to decrease operational risks associated with environmental compliance and resource constraint. Considering these benefits, it is posited that the use of GP techniques positively influences OP. This idea is corroborated by recent findings demonstrating that GP can enhance both environmental and economic outcomes for enterprises by promoting efficiency and sustainability in their operations (Khan *et al.*, 2023).

H1: Green Procurement (GP) positively impacts Operational Performance (OP).

EFP denotes the utilization of materials and design methodologies that mitigate environmental effect, diminish waste, and foster sustainability across the packaging life cycle. In the agro-processing and food sector, where packaging is crucial for maintaining product quality and safeguarding consumer safety, the transition to sustainable packaging has become a vital component of GSCM (du Plessis *et al.*, 2023). EFP encompasses strategies including employing biodegradable materials, utilizing recyclable packaging, and diminishing the total weight and volume of packing to enhance resource efficiency and reduce waste. These techniques not only promote environmental sustainability but also possess considerable potential for improving OP. The correlation between EFP and OP is well-documented in the literature. Companies that implement EFP can achieve cost savings due to the reduced energy requirements for the production and transportation of sustainable materials. Moreover, sustainable packaging can decrease waste disposal expenses and enhance resource efficiency by reducing the necessity for packaging waste management. These operational improvements significantly enhance the firm's overall performance by decreasing operational expenses and increasing profitability. The implementation of EFP corresponds with increasing customer demand for environmentally responsible products, thereby strengthening a company's reputation and brand equity. This can result in enhanced market share and customer loyalty, which are essential factors for operational success (Rashid *et al.*, 2020). Moreover, EFP is frequently linked to regulatory adherence, as governmental and international entities increasingly mandate that enterprises implement sustainable practices. This proactive compliance strategy can assist organizations in evading fines and sanctions, hence enhancing their overall operational stability and performance. The implementation of EFP by agro-processing enterprises in Bangladesh can significantly enhance OP by mitigating environmental hazards, maximizing resource utilization, and bolstering brand equity. By reducing packaging waste and enhancing sustainability practices, companies can achieve efficiencies that directly influence their OP. Considering these factors, it is posited that EFP positively influences OP. This concept aligns with previous research indicating that sustainable packaging can enhance operational efficiencies, lower costs, and boost market competitiveness, therefore improving a firm's overall performance (Afif *et al.*, 2022).

H2: Eco-Friendly Packaging (EFP) positively impacts Operational Performance (OP).

WME denotes the efficacy with which a company administers its trash, emphasizing the reduction, reuse, and recycling of waste materials to mitigate environmental impact and enhance operational efficiency. Efficient waste management is essential in the agro-processing and food business due to the substantial quantities of by-products, food waste, and packaging waste produced during production and distribution (Hoang *et al.*, 2023). Sustainable waste management approaches, including the implementation of waste-to-energy technologies, recycling initiatives, and trash reduction strategies, can enhance both environmental and operational results. The correlation between WME and OP is well-documented in the literature. Companies that use efficient waste management practices can save operational expenses by minimizing disposal costs, enhancing resource efficiency, and reclaiming value from waste products (İncekara, 2022). By reducing waste production, companies can decrease raw material charges, energy usage, and storage costs, resulting in enhanced profitability and operational efficiency (Nikolicic *et al.*, 2021). Moreover, effective waste management improves corporate performance by assuring adherence to regulations, minimizing the danger of environmental penalties, and alleviating adverse effects on the company's reputation. This mitigates operational risks and facilitates more seamless daily operations. Beyond cost savings, WME enhances supply chain performance by promoting sustainability across the value chain. Through collaboration with suppliers and customers on waste reduction projects, companies can promote resource efficiency, fortify supplier relationships, and improve overall supply chain performance (Andalib Ardakani *et al.*, 2023). In Bangladesh's agro-processing sector, where waste disposal and resource management are critical issues, effective waste management strategies can substantially enhance OP by minimizing inefficiencies and optimizing resource use. Furthermore, the effectiveness of waste management enhances environmental performance, potentially resulting in competitive benefits in the marketplace. Increasing consumer and regulatory demands for sustainable practices necessitate the enhancement of waste management systems, which can bolster a firm's brand image, attract environmentally concerned consumers, and ensure compliance with environmental rules. These elements enhance operational stability and overall efficacy. It is posited that the effectiveness of waste management has a favorable effect on OP. Recent studies substantiate this idea, demonstrating that companies implementing efficient waste management strategies not only decrease expenses but also enhance their operational sustainability and performance (Farooq *et al.*, 2022).

H3: Waste Management Efficiency (WME) positively impacts Operational Performance (OP).

SEC denotes the proactive alliance between a company and its suppliers to collectively devise and execute environmentally friendly policies throughout the supply chain. This partnership may encompass various projects, including the exchange of knowledge regarding green technologies, joint efforts in eco-friendly product design, the implementation of sustainable sourcing procedures, and the optimization of logistics to minimize carbon footprints. Within the agro-processing and food sector, SEC can improve operational efficiency by cultivating robust supplier relationships, mitigating supply chain risks, and advancing sustainability (Tukamuhabwa, 2023). The influence of supplier environmental collaboration on OP is well recorded in the literature. Companies that participate in collaborative environmental projects with their suppliers are more likely to improve their OP through enhanced supply chain efficiency, cost savings, and innovation in sustainable practices (Sudusinghe & Seuring, 2022). Collaborations enable enterprises to secure environmentally sustainable raw materials, minimize waste and energy usage, and enhance the efficiency of their production processes. This collaboration with suppliers enhances organizations' ability to satisfy regulatory and consumer demands while fostering the creation of more efficient and robust supply networks. Engaging with suppliers on environmental matters offers companies chances for collaborative innovation, including the advancement of green technologies and the establishment of more sustainable production methods. This innovation can augment OP by enhancing product quality, decreasing expenses, and elevating the speed and adaptability of manufacturing (Siagian *et al.*, 2021). Furthermore, SEC can alleviate supply chain disruptions by guaranteeing a more sustainable and dependable supply of raw materials, which is especially vital in sectors like agro-processing, where continuity is essential for sustaining operational efficiency (Božić *et al.*, 2025). Furthermore, SEC can enhance reputational advantages, since companies who partner with suppliers to adopt environmentally sustainable practices are frequently perceived more positively by consumers, regulators, and other stakeholders. An improved reputation can result in heightened customer loyalty, expanded market share, and superior financial performance, hence positively influencing operational results (Khan *et al.*, 2022). In Bangladesh's agro-processing sector, where environmental sustainability is gaining prominence, forging successful partnerships with suppliers about green practices can result in cost reductions, enhanced resource efficiency, and superior market positioning. Consequently, it is plausible to postulate that supplier environmental collaboration enhances OP.

H4: Supplier Environmental Collaboration (SEC) positively impacts Operational Performance

(OP).

TAGP refers to the integration of innovative and TAGP denotes the incorporation of innovative and sustainable technology into company operations to enhance environmental performance and efficiency. These technologies may encompass renewable energy systems, energy-efficient machinery, waste-to-energy solutions, sophisticated recycling procedures, and software applications for environmental data management (Farghali & Osman, 2024). In the agro-processing and food industry, where resource consumption, waste generation, and environmental impact are critical issues, the implementation of green technologies can significantly enhance OP by increasing resource efficiency, lowering costs, and ensuring adherence to environmental regulations (Umar *et al.*, 2022). The correlation between TAGP and OP is well-documented in the literature. Research indicates that the use of green technologies enhances operational effectiveness via multiple processes. The implementation of energy-efficient technologies can substantially lower energy expenditure, a crucial element of operational costs across various businesses. Furthermore, technologies that improve waste management or facilitate recycling can result in cost reductions by lowering trash disposal expenses and allowing companies to reclaim value from materials that were previously dumped. By diminishing energy consumption and trash production, companies not only decrease operational expenses but also enhance their resource efficiency, resulting in superior overall performance (Pimenov *et al.*, 2022). Furthermore, the incorporation of green technologies allows companies to comply with regulatory standards and meet consumer demands for sustainability. Companies that implement innovative environmental technology are more adept at complying with severe environmental rules and leveraging the rising customer demand for sustainable products (Zhong & Um, 2025). This may result in an improved brand image, heightened consumer loyalty, and augmented market competitiveness—elements that boost OP. The implementation of green technology can stimulate innovation in companies, resulting in enhancements in product quality, supply chain efficiency, and production methods. By employing advanced technology, companies can optimize processes, minimize waste, and improve product quality, hence enhancing OP (Ammar *et al.*, 2021). Agro-processing enterprises in Bangladesh face considerable issues with resource scarcity, waste management, and environmental restrictions; thus, the implementation of green technologies might confer a competitive advantage. Enhancing environmental sustainability and operational efficiency enables enterprises to get superior financial and operational results, becoming the implementation of green technology an essential catalyst for operational success. Considering these considerations, it is posited that the integration of technology in sustainable practices positively influences OP. This concept aligns with recent data indicating that the incorporation of green technologies results in cost reductions, operational efficiencies, and enhanced sustainability, all of which increase overall performance (Lerman *et al.*, 2022).

H5: Technological Adoption in Green Practices (TAGP) positively impacts Operational Performance (OP).

2.2.1 Mediating effects of Technological Adoption in Green Practices

GP denotes the strategic method of acquiring ecologically sustainable materials, products, or services that fulfill the organization's sustainability goals and comply with regulatory standards. In the agro-processing and food sector, GP procedures can markedly diminish the environmental impact of operations by guaranteeing that raw materials, packaging, and other supplies are sourced sustainably, hence reducing waste and energy consumption (Simane *et al.*, 2024). Nonetheless, the simple implementation of green buying does not inherently result in enhanced OP. Organizations must implement technical solutions to fully achieve their green buying objectives. The adoption of technology in sustainable practices (TAGP) is pivotal in this setting. The use of green technology, including energy-efficient procurement systems, sustainable material tracking, and EFP technologies, improves the efficacy of GP techniques. Information systems that monitor supplier sustainability or technologies that facilitate the efficient utilization of raw materials can enhance firms' procurement processes, ensuring that environmentally responsible sourcing practices yield measurable operational improvements (Fallahpour *et al.*, 2021). TAGP offers the resources and functionalities essential for enhancing sustainable buying practices. Automated systems can discern and choose suppliers based on environmental performance measures, while sophisticated logistics technology can optimize supply chains to minimize energy usage and transportation expenses (Emon, 2025c). These technologies enhance the efficiency of the procurement process and assist organizations in minimizing costs, waste, and emissions related to sourcing, thereby directly influencing OP. The effective integration of green technologies in the procurement process allows companies to more effectively mitigate risks associated with environmental legislation and supply chain interruptions. This risk minimization can result in more stable operations, decrease possible expenses related to non-compliance, and enhance overall

supply chain efficiency (Obayi & Ebrahimi, 2021). By equipping GP programs with suitable technology tools, companies can more effectively attain sustainability objectives, minimize operational inefficiencies, and improve long-term performance. The correlation between GP and OP is markedly enhanced when companies implement green technologies. These technologies facilitate the influence of GP on OP by improving the efficacy and efficiency of sustainable procurement procedures. Consequently, the mediating function of TAGP in this connection is crucial for elucidating how GP might beneficially impact operational outcomes. In light of this rationale, the subsequent hypothesis is posited:

H6a: TAGP mediates the relationship between GP and OP.

EFP is a crucial component of sustainable supply chain management, particularly in sectors such as agro-processing and food, where packaging is vital for product safety, preservation, and transportation. EFP employs recyclable, biodegradable, and energy-efficient materials that mitigate the environmental impact of packaging while preserving functionality and product integrity (Olarewaju *et al.*, 2024). Although the adoption of EFP offers evident environmental and regulatory advantages, it is not invariably adequate to independently boost OP. The use of new technologies is essential for optimizing the advantages of sustainable packaging practices. The adoption of TAGP can markedly improve the efficacy of sustainable packaging. Technological instruments, including automated packaging systems, intelligent package designs, and waste-minimizing technologies, enhance the packaging process, increase efficiency and decrease material expenses. Technologies facilitating real-time monitoring of packaging material utilization or enabling accurate measurement of necessary packing dimensions can diminish waste, lower expenses, and enhance the overall efficiency of the packaging process. Furthermore, the implementation of green technology, including biodegradable materials and energy-efficient manufacturing methods, directly advances the objectives of EFP by minimizing the environmental impact linked to packaging production and disposal (Wandosell *et al.*, 2021). These technologies allow companies to monitor and enhance the environmental impact of their packaging solutions, assuring compliance with sustainability objectives while maintaining operational efficiency. Furthermore, advancements in digital technologies such as IoT sensors facilitate the real-time monitoring and regulation of the quality and integrity of EFP, thereby ensuring that packaging solutions are efficient and positively impact product quality, ultimately improving operational outcomes. Furthermore, TAGP can significantly contribute to overcoming the obstacles companies encounter in implementing sustainable packaging. The implementation of supply chain management systems emphasizing eco-efficient packaging solutions can decrease material expenses, optimize packaging processes, and alleviate supply chain inefficiencies (Menon & Ravi, 2021). Moreover, technology enhances adherence to environmental standards, mitigating fines, bolstering brand reputation, and eventually fostering a more competitive market stance. TAGP increases the connection between sustainable packaging and OP by optimizing package efficiency, minimizing waste, and ensuring regulatory compliance. This mediation assists companies with guaranteeing that their investment in environmentally sustainable packaging produces quantifiable enhancements in productivity, cost efficiency, and sustainability. Consequently, technological adoption is an essential facilitator that connects EFP with enhanced operational results. In light of this reasoning, the subsequent hypothesis has been laid forth:

H6b: TAGP mediates the relationship between EFP and OP.

WME is essential for improving the OP of companies in the agro-processing and food sectors, particularly due to the substantial waste produced during production, processing, and packaging. Efficient waste management diminishes environmental effect and assists companies in lowering operational expenses by decreasing trash disposal costs, augmenting material recovery, and improving overall resource efficiency (Mostaghimi & Behnamian, 2023). Nonetheless, although WME offers distinct environmental and economic advantages, its complete potential is frequently limited by the absence of sophisticated technologies that might enhance waste tracking, treatment, recycling, and disposal methodologies. The adoption of TAGP can significantly boost waste management by using new solutions that improve trash reduction, recycling, and reuse. Technologies include waste-to-energy systems, automated trash sorting technologies, and intelligent waste tracking systems allow companies to enhance waste management, reclaim valuable resources, and minimize operational inefficiencies. By implementing these technologies, companies can enhance waste stream management, reduce their carbon footprint, and optimize operational efficiency in ways unattainable through conventional waste management practices (Firoozi *et al.*, 2024). Advanced recycling methods facilitate the efficient processing of materials that would otherwise be abandoned, hence diminishing landfill waste and minimizing disposal expenses. Waste-to-energy systems can transform organic waste into renewable energy, offering companies a sustainable power source that diminishes operational expenses and dependence on external energy suppliers (Hsu *et al.*, 2024). Automated trash sorting and tracking systems can improve operational efficiency by lowering personnel expenses, increasing waste segregation

precision, and optimizing the movement of waste materials in the recycling process Moreover, the implementation of green technologies in waste management assists companies in adhering to progressively rigorous environmental requirements and consumer demands for sustainability. Regulatory compliance prevents enterprises from incurring fines and reputational harm, while sustainable waste management methods improve the firm's market competitiveness (Ma *et al.*, 2021). By using TAGP, companies can enhance their environmental sustainability while simultaneously optimizing operational efficiency, positioning waste management as a critical domain where technological integration directly influences performance outcomes. TAGP facilitates the connection between WME and OP by enhancing waste management processes. This mediation enables companies to attain improved operational efficiency, cost reductions, and regulatory adherence while bolstering their environmental sustainability. Thus, technological adoption serves as a vital facilitator that enhances the efficacy of waste management in optimizing OP. Consequently, this rationale leads to the formulation of the subsequent hypothesis:

H6c: TAGP mediates the relationship between WME and OP.

SEC denotes the cooperative initiatives of enterprises and their suppliers to adopt environmentally sustainable practices throughout the supply chain. In the agro-processing and food sector, SEC is crucial for guaranteeing that environmental sustainability transcends the business, hence fostering a more comprehensive green supply chain. Collaboration with suppliers in sustainable sourcing, waste reduction, and energy efficiency can markedly enhance the environmental performance of the supply chain while simultaneously improving operational efficiency by lowering costs, elevating product quality, and increasing supplier reliability (Feng *et al.*, 2024). Nonetheless, the efficient execution of SEC frequently necessitates the incorporation of technology to facilitate communication, oversight, and alignment of environmental objectives between enterprises and their suppliers. Technological instruments, like cloud-based platforms for real-time data dissemination, supplier performance evaluation systems, and collaborative design applications, are essential for navigating the intricacies of SEC. These tools enable companies to monitor supplier sustainability performance, exchange best practices, and promote collaborative creation of environmentally friendly solutions (Mishra *et al.*, 2022). In the absence of technology support, the prospective advantages of SEC may remain unactualized due to challenges such as communication inefficiencies, insufficient transparency, or complications in monitoring environmental performance throughout the supply chain. TAGP facilitates the connection between Supply Chain Efficiency (SEC) and OP by fostering more efficient and transparent communication with suppliers. By employing new technologies like data analytics, cloud computing, and blockchain, companies can monitor the environmental effects of their supply chain operations and verify that suppliers adhere to established sustainability criteria. These technologies improve the decision-making process by delivering real-time insights about supplier performance, resulting in enhanced collaboration, diminished risks, and more informed resource allocation decisions (Unhelkar *et al.*, 2022). Furthermore, TAGP can facilitate the scaling of organizations' SEC initiatives by automating essential activities, including supplier selection, performance evaluation, and reporting. Suppliers that fulfill sustainability criteria can be automatically chosen via an eco-rating system, and their advancement towards sustainability objectives can be perpetually tracked through a digital portal. This technological integration enhances the efficiency and transparency of the SEC while enabling enterprises to sustain competitive advantages by aligning their supply chains with contemporary environmental regulations and consumer expectations (McGrath *et al.*, 2021). Moreover, technological adoption enables companies to cultivate enduring connections with suppliers by equipping them with the tools essential for collaborative problem-solving and the co-creation of sustainable practices. By enhancing communication and collaborative innovation, companies and suppliers can attain greater operational efficiency, reduced costs, and superior environmental performance, ultimately resulting in increased OP (Fontoura & Coelho, 2022). The relationship between SEC and OP is considerably mediated by the deployment of green technology, which augment collaborative effectiveness and boosts overall performance outcomes. Technology facilitates a more streamlined, transparent, and efficient approach to managing supplier relationships, resulting in enhanced operational efficiency and environmental sustainability. Consequently, the subsequent hypothesis is posited:

H6d: TAGP mediates the relationship between Supplier Environmental Collaboration (SEC) and Operational Performance (OP).

Based on the above discussion, the conceptual framework is presented in Figure 1.

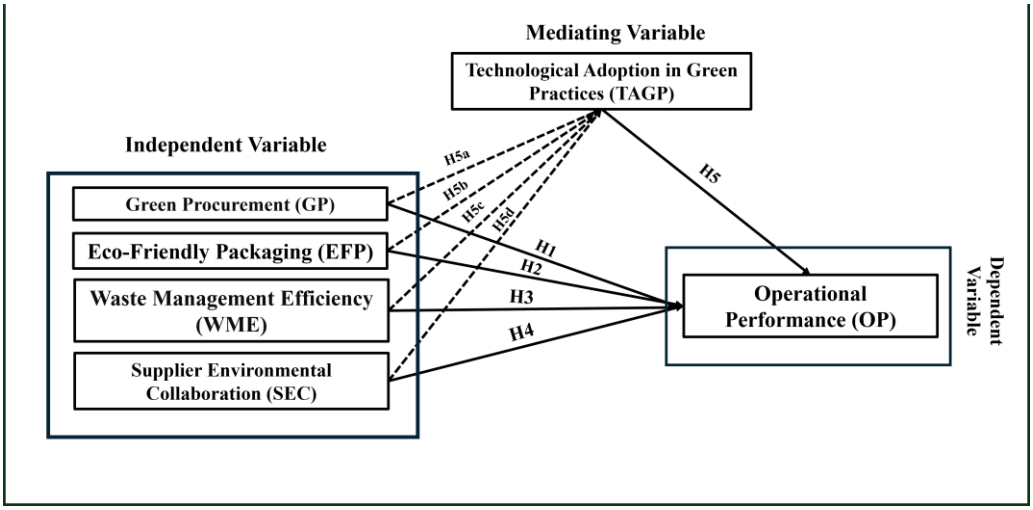

Figure 1 - Conceptual Framework

3. MATERIALS AND METHOD

The study utilized a quantitative methodology to examine the influence of GSCP and technological adoption on OP within the agro-processing and food sector in Bangladesh. A questionnaire served as the principal data collection instrument, given to 325 firms within the agro-processing and food industry. This sample encompassed both SMEs and bigger corporations, reflecting a varied array of organizational sizes and their differing degrees of implementation of green supply chain techniques. Following the distribution of the questionnaires, 254 responses were obtained; however, 11 were removed due to incomplete or inconsistent data, resulting in 243 valid responses for analysis.

This study's unit of analysis was the corporation, focusing on the relationship between GSCP, technological adoption, and operational success at the organizational level. The study population comprised agro-processing and food sector enterprises in Bangladesh, chosen for their pertinence to the research aims and their engagement in sustainable practices and green initiatives. The chosen companies intended to encompass a diverse array of experiences and viewpoints regarding the incorporation of sustainable practices and technological implementation within the industry.

The sample was selected via convenience sampling. This sampling technique was selected for its practicality and the researchers' capacity to engage a diverse array of enterprises within the agro-processing and food sector. Convenience sampling enabled the researchers to choose organizations that were easily accessible and amenable to participating in the study. Although convenience sampling has benefits regarding accessibility and efficiency, it also has drawbacks concerning generalizability, since it may not adequately reflect the complete population of enterprises within the agro-processing and food industry (Nguyen-Thi-Thuy *et al.*, 2024). To address this limitation and improve transparency, we acknowledge that future studies could adopt probability-based or stratified sampling methods to enhance representativeness.

The data collection instrument was a structured questionnaire with closed-ended questions utilizing a five-point Likert scale, from strongly agree to strongly disagree. For greater clarity, PLS-SEM (Partial Least Squares Structural Equation Modeling) was selected as the primary analytical tool because it can simultaneously assess measurement and structural models, manage complex relationships among multiple constructs, and handle smaller sample sizes or non-normal data distributions. The questionnaire aimed to gather data on GP, sustainable packaging, waste management efficacy, supplier environmental cooperation, technological integration in eco-friendly activities, and operational effectiveness. The implementation of a Likert scale enabled participants to indicate their degree of agreement or disagreement with many assertions, yielding quantifiable data for study (Anjaria, 2022). A pre-test step was implemented to enhance the questionnaire and verify its clarity, relevance, and validity. Expert feedback was obtained from professionals in the agro-processing sector and academic researchers, resulting in the alteration of several elements to improve their accuracy and relevance. This additional information about the pre-test and expert feedback improves methodological transparency and demonstrates the rigor of the questionnaire design. This method ensured that the questionnaire effectively captured the essential factors under examination and that respondents could comprehend and reply to the questions with ease. The measuring scale employed in the study was validated via expert feedback, and the final instrument's reliability was assessed using Cronbach's alpha, a standard method for evaluating the internal consistency of scales (Charette *et al.*, 2020). The outcomes of the pre-test

and reliability assessments indicated that the measuring scale was both reliable and valid for this study's objectives.

The data were gathered by questionnaire distribution, and replies were encoded for input into statistical analysis software. After coding the data, it was sanitized and examined for any missing values or anomalies to guarantee the dataset's accuracy and quality. The study utilized SmartPLS 4, a software application specifically developed for PLS-SEM, for data analysis. PLS-SEM is especially advantageous for examining intricate correlations among numerous constructs, as it enables researchers to simultaneously model both measurement and structural relationships. PLS-SEM was selected for its capacity to manage small to medium sample numbers and its effectiveness in estimating intricate models with non-normal data distributions (Batra, 2025). Providing this explanation enhances clarity for readers unfamiliar with PLS-SEM and strengthens the methodological transparency of the study. The analysis concentrated on evaluating the proposed hypotheses and investigating the mediating function of technological adoption in sustainable practices. SmartPLS was employed to assess the relationships among the independent variables (GP, EFP, WME, and supplier environmental collaboration), the mediating variable (TAGP), and the dependent variable (OP). The software generated estimates for path coefficients, loadings, and significance levels, which were utilized to ascertain the strength and direction of the correlations among the variables. The findings were further analyzed to evaluate the influence of GSCP and technological implementation on OP within the agro-processing and food sector in Bangladesh. The use of SmartPLS as the statistical method for data analysis was warranted due to its capacity to facilitate a thorough investigation of the intricate interactions among the variables, encompassing both direct and indirect impacts. This method enabled the study to investigate both the direct influence of GSCP on OP and the mediating effect of technological adoption, yielding profound insights into the sustainability dynamics within the agro-processing and food sector (Jain *et al.*, 2025). Table 1 exhibits the internal consistency reliability of the measuring scales employed in this work, as evidenced by Cronbach's alpha coefficients. Cronbach's alpha is a recognized statistical measure for evaluating the internal consistency of survey instruments, with values beyond 0.70 deemed acceptable, those above 0.80 regarded as good, and values surpassing 0.90 indicative of outstanding reliability (Hair & Alamer, 2022). All six constructs GP, EFP, WME, SEC, TAGP, and OP demonstrate exceptional reliability, with Cronbach's alpha values between 0.92 and 0.94. The elevated values signify that the measurement items within each construct are strongly interconnected and reliably assess the target notion. The construct EFP attained an alpha of 0.93, indicating robust internal consistency among the items evaluating sustainable packaging practices. Correspondingly, TAGP achieved an alpha of 0.94, affirming that the scale effectively measures the technological integration endeavors within green initiatives. The findings indicate that the instrument employed in the study is statistically valid and capable of yielding reliable and consistent measurements across all primary variables, so establishing a solid basis for subsequent structural analysis via SEM.

Table 1 - Reliability of the Measurements

Constructs	No. of Items	Cronbach's Alpha
Green Procurement (GP)	6	0.94
Eco-Friendly Packaging (EFP)	6	0.93
Waste Management Efficiency (WME)	5	0.94
Supplier Environmental Collaboration (SEC)	5	0.94
Technological Adoption in Green Practices (TAGP)	5	0.94
Operational Performance (OP)	5	0.93

4. RESULTS

Table 2 provides an overview of the demographic attributes of the 243 participants from the agro-processing and food sector in Bangladesh. The gender breakdown reveals a male-dominated workforce, including 67.5% males and 32.5% females. The predominant age group is 31–40 years (52.6%), indicating that most respondents are early to mid-career professionals, a trend typical in industries experiencing modernization and technological advancement. A majority (59.7%) own a bachelor's degree, while a substantial proportion (34.6%) holds a master's degree, reflecting a highly educated respondent pool. A little segment (5.7%) has undertaken specialized courses in supply chain management, indicating focused professional advancement in sustainability and logistics. Mid-level personnel constitute the majority of the sample at 51.8%, followed by senior-level employees at 37.9%, thereby providing a strategic view on operational and technological matters. Entry-level personnel constitute a mere 10.3%, offering a more operational perspective. The majority of participants are from the agro-processing sector (65.5%), followed by food

processing (23.5%), with a minor segment (11.1%) engaged in both, illustrating the diversity of operational contexts addressed in the study. Significantly, more than half of the participants (51.4%) indicate moderate acceptance of green technology, whereas 32.1% exhibit low adoption and merely 16.5% demonstrate high adoption levels, underscoring potential for technological progress. The bulk are located in the Dhaka Division (59.7%), indicating its economic and industrial prominence, while the remainder (40.3%) comes from the Chittagong Division, another region of industrial significance. These demographics offer a comprehensive and pertinent foundation for examining green supply chain strategies and technological integration within the Bangladeshi setting.

Table 2 - Demographic Profile of Respondents in the Agro-Processing and Food Sector

Variable	Category	Frequency	Percent
Gender	Male	164	67.5%
	Female	79	32.5%
Age	21–30 Years	72	29.6%
	31–40 Years	128	52.6%
	41–50 Years	36	14.8%
	50 and above Years	7	2.9%
Education Level	Bachelor's Degree	145	59.7%
	Master's Degree	84	34.6%
	Supply chain specialized course	14	5.7%
Employment Status	Entry-Level Employee	25	10.3%
	Mid-Level Employee	126	51.8%
	Senior-Level Employee	92	37.9%
Industry Sector	Agro-Processing	159	65.5%
	Food Processing	57	23.5%
	Both	27	11.1%
Technology Adoption in Practices	Low Adoption	78	32.1%
	Moderate Adoption	125	51.4%
	High Adoption	40	16.5%
Geographical Location	Dhaka Division	145	59.7%
	Chittagong Division	98	40.3%
Total		**243**	**100%**

Table 3 illustrates the findings of the measurement model evaluation, encompassing the factor loadings of individual items, Average Variance Extracted (AVE), and Composite Reliability (CR) for all constructs in the research. The structural equation model needs these indicators to validate construct convergent validity as well as measure its internal consistency and dependability. The assessment of convergent validity examines the statistical connection strength between theoretical dimensions that belong to the same construct. The AVE measurement from Fornell and Larcker (1981) requires a value above 0.50 to establish convergent validity. The constructs GP, EFP, WME, SEC, TAGP and OP derive AVE values that surpass the 0.50 threshold with a scope of 0.75 to 0.81 (see Table 3). Each set of variables demonstrates sufficient representation of its corresponding construct according to the findings. The researchers adopted CR to evaluate internal consistency reliability because PLS-SEM prefers it over Cronbach's alpha specifically (Hair & Alamer, 2022).

The study considers 0.70 or higher CR values as satisfactory. The CR values exceed 0.90 for all conceptions during this analysis which indicates a superior level of reliability and internal construct consistency (Fornell & Larcker, 1981; Hair & Alamer, 2022). The CR values demonstrate that all Constructs show high reliability because GP has 0.94 whereas EFP has 0.93 and WME exhibits 0.94. This confirms indicators properly measure their respective constructs. Moreover, the examined dimensions of the measurement model demonstrate item loadings exceeding 0.70 as per (Hair Jr *et al.*, 2020) while most of the items show values greater than 0.85. High values of factor loading indicate that each item strongly measures its associated latent construct. The components within the GP show a range between 0.81 and 0.93 thus indicating solid individual contribution to theoretical construct validity. The results presented in Table 3 validate the good convergent validity and internal consistency reliability of the measurement model, confirming that the Constructs are

accurately measured and dependable for subsequent structural model analysis. These findings provide a robust basis for assessing the correlations among GSCP, technological adoption, and operational effectiveness within the agro-processing and food sector in Bangladesh.

Table 3 - Measurement Model

Constructs	Items	Loading	AVE	CR
Green Procurement (GP)	GP1	0.86	0.78	0.94
	GP2	0.90		
	GP3	0.93		
	GP4	0.88		
	GP5	0.81		
	GP6	0.91		
Eco-Friendly Packaging (EFP)	EFP1	0.81	0.75	0.93
	EFP2	0.84		
	EFP3	0.88		
	EFP4	0.89		
	EFP5	0.88		
	EFP6	0.88		
Waste Management Efficiency (WME)	WME1	0.91	0.81	0.94
	WME2	0.95		
	WME3	0.89		
	WME4	0.88		
	WME5	0.88		
Supplier Environmental Collaboration (SEC)	SEC1	0.89	0.80	0.94
	SEC2	0.89		
	SEC3	0.87		
	SEC4	0.90		
	SEC5	0.91		
Technological Adoption in Green Practices (TAGP)	TAGP1	0.93	0.81	0.94
	TAGP2	0.89		
	TAGP3	0.89		
	TAGP4	0.88		
	TAGP5	0.91		
Operational Performance (OP)	OP1	0.89	0.78	0.93
	OP2	0.91		
	OP3	0.88		
	OP4	0.84		
	OP5	0.90		

Table 4 provides the results of the discriminant validity evaluation according to the Fornell-Larcker criterion, a widely recognized method for assessing the distinctiveness of latent components inside a measurement model. Discriminate validity is established when the square root of the AVE for each construct, indicated in bold diagonally, exceeds its correlations with other constructs in the corresponding row and column. This approach guarantees that a latent construct exhibits greater variance with its corresponding measurement items than with those of alternative constructs (Emon & Khan, 2025a; Fornell & Larcker, 1981; Hair Jr *et al.*, 2020).

This study found that all Constructs satisfactorily met the criteria, proving that each variable in the model exhibits sufficient discriminant validity. The measurement method of GP exhibits a square root of 0.88 AVE that surpasses or matches its connections with EFP at 0.93, WME at 0.75, SEC at 0.88, TAGP at 0.91, and OP at 0.90. The reported moderate relationships between GP and EFP and GP and TAGP are justified by the theoretical connection between these constructs in GSCP and technological adoption contexts (Emon & Chowdhury, 2025). The square root of AVE for TAGP equals 0.90 although it is slightly less than the value of 0.95 found between TAGP and OP. Theoretical evidence supports the close link between TAGP and OP because TAGP acts as a vital enabler of OP for green supply chains. Discriminant validity remains intact even though the 0.90 correlation score suggests robustness and can be supported by theoretical foundations and

supplemental validity tests involving composite reliability and factor loadings (Hair & Alamer, 2022; T. Khan *et al.*, 2024). The findings confirm that each construct in the model is conceptually unique, validating the incorporation of all variables in the structural model and reinforcing the validity of the hypothesis testing. The satisfactory discriminant validity established by the Fornell-Larcker criterion enhances trust in the structural equation modeling results and substantiates the theoretical premises underlying the links among green practices, technological uptake, and performance outcomes.

Table 4 - Discriminant Validity Assessment Using Fornell-Larcker Criterion

Constructs	GP	EFP	WME	SEC	TAGP	OP
GP	0.88					
EFP	0.93	0.86				
WME	0.75	0.78	0.90			
SEC	0.88	0.89	0.78	0.89		
TAGP	0.91	0.92	0.81	0.93	0.90	
OP	0.90	0.94	0.79	0.92	0.95	0.88

Table 5 illustrates the results of hypothesis testing via structural equation modeling employing Smart PLS. The table contains the association path, t-values, p-values, and the determination of hypothesis endorsement. These values ascertain the robustness and importance of direct and mediating links among GSCP, technological uptake, and OP. EFP and SEC exhibited substantial positive impacts on OP, with t-values of 4.55 (p = 0.00) and 2.40 (p = 0.02), respectively. The findings suggest that observable and cooperative green practices are more likely to improve performance, potentially due to their direct operational significance and heightened stakeholder engagement. Conversely, the findings indicate that the direct correlation between GP and OP is not statistically significant (t = 0.10, p = 0.92), suggesting that GP independently does not substantially enhance operational outcomes in the examined environment. Likewise, WME did not demonstrate a significant direct effect on OP (t = 0.36, p = 0.72). The findings indicate that although these practices are significant elements of GSCM, their individual impact may be inadequate to directly enhance OP without supplementary mechanisms like technology.

The use of TAGP has considerably influenced OP (t = 4.33, p = 0.00), affirming its function as a vital facilitator of operational efficiency. The mediation analysis indicated that TAGP significantly mediates all four links between green practices and performance. The mediating effect of TAGP was significant for GP (t = 2.50, p = 0.01), EFP (t = 2.25, p = 0.02), WME (t = 1.96, p = 0.05), and SEC (t = 6.42, p = 0.00). However, to present a more balanced interpretation and avoid overstating causality, it should be noted that while TAGP facilitates the transformation of non-significant practices into measurable performance outcomes, this does not imply a direct causal effect in isolation other contextual factors may also contribute to the observed results. These findings corroborate the theoretical rationale of the TOE framework and the RBV, which assert that technological integration allows organizations to convert environmental practices into measurable performance advantages (Emon, 2025a; Tornatzky & Fleischer, 1990).

Table 5 - Hypothesis Testing

Hypothesis	Relationship	T Value	P Value	Remarks
H1	GP → OP	0.10	0.92	Not Supported
H2	EFP → OP	4.55	0.00	Supported
H3	WME → OP	0.36	0.72	Not Supported
H4	SEC → OP	2.40	0.02	Supported
H5	TAGP → OP	4.33	0.00	Supported
H6a	GP → TAGP → OP	2.50	0.01	Supported
H6b	EFP → TAGP → OP	2.25	0.02	Supported
H6c	WME → TAGP → OP	1.96	0.05	Supported
H6d	SEC → TAGP → OP	6.42	0.00	Supported

Table 6 exhibits the coefficient of determination (R^2) values for the endogenous Constructs: OP and TAGP. R^2 quantifies the fraction of variance in the dependent variable elucidated by the independent variables within the model. An R^2 value approaching 1 signifies a greater explanatory capacity of the model (Hair & Alamer, 2022; Khan & Hasan Emon, 2024).

The R^2 value for OP is 0.93, with an adjusted R^2 also at 0.93. This indicates that 93% of the variance in OP is accounted for by the predictors in the model: GP, EFP, WME, SEC, and TAGP. The elevated R^2 value indicates the significant predictive usefulness of these factors in elucidating operational outcomes within the agro-processing and food industry setting of Bangladesh. The integration of green supply chain methods, especially when augmented by technology, can markedly enhance operational efficiency and performance.

The R^2 for TAGP is 0.91, with an adjusted R^2 of 0.91, signifying that 91% of the variance in TAGP is elucidated by the four constructs of green practices (GP, EFP, WME, and SEC). This significant number indicates that the model successfully identifies the factors influencing technological adoption in green efforts, highlighting the essential role of various elements of GSCM in facilitating technological integration. The elevated R^2 values provide robust validation for the theoretical frameworks employed in this study specifically the TOE framework, the RBV, and the NRBV which collectively assert that internal capabilities and external pressures affect both technological adoption and performance outcomes (Barney, 1991; Tornatzky & Fleischer, 1990). In conclusion, the R^2 statistics validate the robustness of the proposed model and emphasize the strategic significance of green and technology practices in attaining superior OP.

Table 6 - Coefficient of Determination (R^2) for Endogenous Constructs

Constructs	R^2	R^2 adjusted
OP	0.93	0.93
TAGP	0.91	0.91

Figure 2 illustrates the findings of the PLS-SEM, depicting the interrelations among GSCP, technological adoption, and OP. The model comprises a measurement model that evaluates the reliability and validity of Constructs, and a structural model that estimates the strength and direction of hypothesized links among latent variables. This figure demonstrates that each latent construct GP, EFP, WME, SEC, TAGP, and OP is assessed through multiple indicators exhibiting high factor loadings, between 0.81 and 0.95. This validates robust convergent validity and internal consistency, as all loadings surpass the advised criterion of 0.70 (Hair *et al.*, 2020). For instance, GP is consistently quantified by six indicators (GP1–GP6) exhibiting loadings ranging from 0.86 to 0.93, while OP is evaluated through five indicators (OP1–OP5), each demonstrating robust loadings above 0.84. The internal structural model emphasizes various critical relationships. TAGP significantly enhances OP, evidenced by a path coefficient of 0.43. This indicates that the implementation of green technologies markedly improves operational efficiency and effectiveness. Likewise, EFP exhibits a significant effect on OP (0.39), suggesting that sustainable packaging enhances performance outcomes. SEC had the most significant impact on TAGP at 0.42, followed by WME at 0.24 and GP at 0.22. These findings indicate that both internal and external green practices promote technology adoption, therefore enhancing operational effectiveness. The direct impacts of GP, WME, and SEC on OP are notably small, with values of -0.01, 0.03, and 0.13, respectively. The minimal or adverse effect of GP on OP may stem from initial economic burdens or implementation difficulties. The weak direct effects substantiate the assertion that TAGP functions as a mediating variable, converting green behaviors into enhancements in performance. This corresponds with the RBV, NRBV and TOE Theory, which highlight the significance of internal capabilities such as technological innovation in securing competitive advantages. The model accounts for 93% of the variance in OP ($R^2 = 0.93$) and 91% of the variance in Technological Adoption ($R^2 = 0.91$), both of which are regarded as exceptionally high. These values indicate that the model possesses exceptional explanatory power and aligns effectively with the data. In summary, Figure 2 illustrates that technological adoption is a vital mediating element in converting green supply chain initiatives into concrete operational results. Organizations seeking to improve their performance should prioritize the integration of modern green technologies and the cultivation of collaborative connections with suppliers to fully leverage the advantages of sustainable practices.

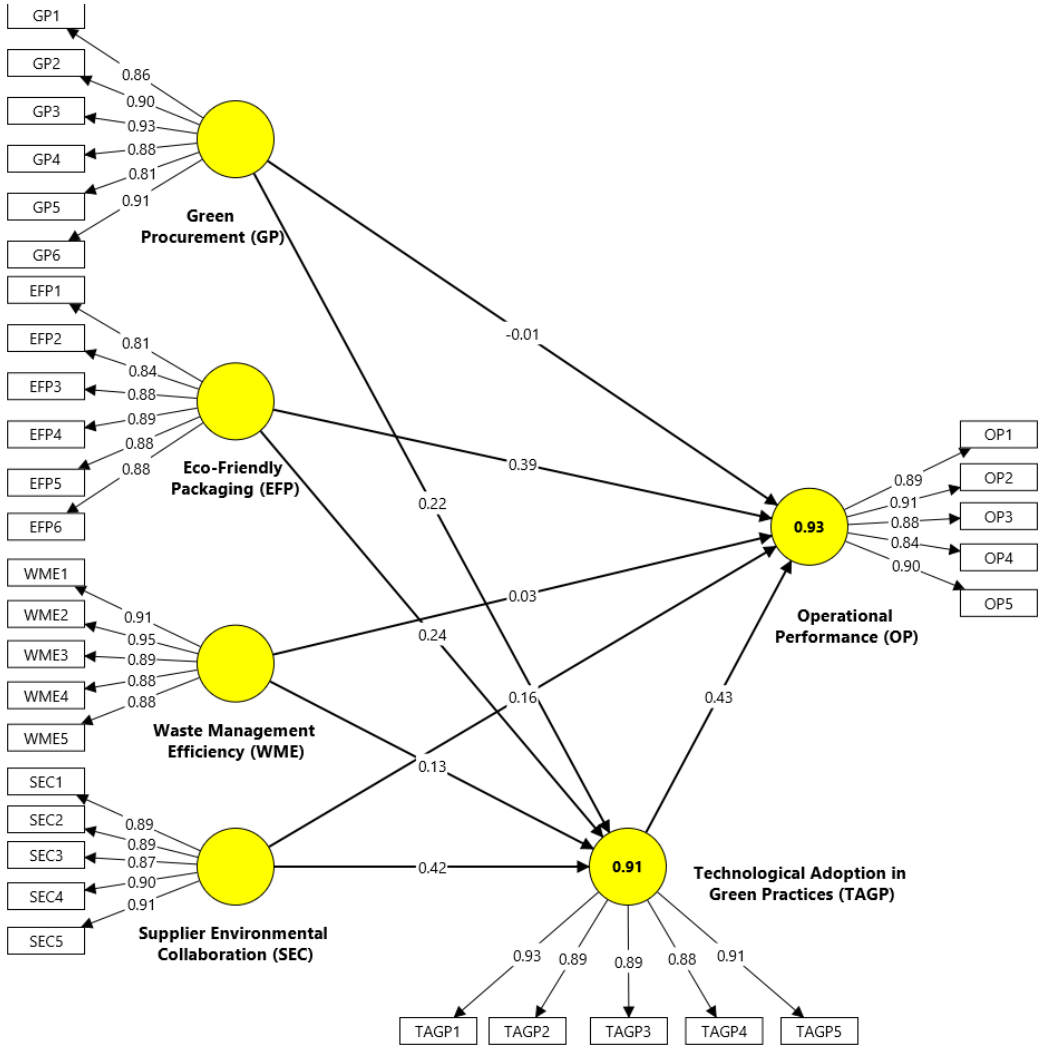

Figure 2 - Structural Equation Model Showing the Path Coefficients (PLS-SEM Approach)

5. DISCUSSION AND IMPLICATIONS

This study intended to investigate the mediating effect of TAGP on the relationship between essential GSCP GP, EFP, WME, and SEC and OP in the agro-processing and food sector in Bangladesh. The study was based on the TOE framework, the RBV, and the NRBV, providing a solid theoretical perspective for examining the interactions among technology, environmental sustainability, and performance. Theoretical foundations indicate that internal resources and technological capabilities are essential drivers for achieving competitive advantage via sustainability (Barney, 1991; Mahdi & Nassar, 2021; Tornatzky & Fleischer, 1990). The study empirically demonstrated that, although direct correlations between GP and WME and OP were not statistically significant, EFP and SEC exerted substantial direct effects on OP. The mediation analysis revealed that TAGP significantly mediated the links between all four green supply chain strategies and OP, including instances where the direct effect was not significant. This discovery highlights the essential function of technical intervention in enhancing the efficacy of green practices, particularly in resource-limited environments such as Bangladesh. The outcome corresponds with the expanding literature that posits technology as a strategic enabler rather than merely a supportive tool in sustainability transitions (Khan & Emon, 2025; Shamsuddoha & Nasir, 2025).

Theoretical, Methodological, and Practical Implications

The study's theoretical contribution is its comprehensive use of the TOE, RBV, and NRBV frameworks within a developing nation environment. It enhances current understanding by demonstrating that technology operates not just as a resource (RBV) and a reaction to environmental pressures (TOE), but also as an environmentally strategic capability (NRBV) that mediates the relationship between green practices and performance. This integration underscores that technology adoption is a crucial gateway that companies must emphasize to obtain operational advantages from sustainability initiatives.

Methodologically, this study shows that using a quantitative approach together with PLS-SEM can be quite effective for analyzing complex mediation models related to sustainability and technology. The application of well-tested measurement scales and mediation analysis provides a useful framework that other researchers can adapt when exploring similar topics in developing or emerging markets. Although the study relied on convenience sampling, the results still offer meaningful insights, mainly because the sample size was sufficient and the data underwent strict reliability and validity checks. This methodological approach could act as a solid foundation for future studies especially those aiming to compare different industries or track changes over time in how technology and environmental management interact.

The study provides practical insights for policymakers, managers, and supply chain professionals in the agro-processing and food sectors. It underscores the necessity for technological expenditures that facilitate green initiatives, like digital monitoring systems, sustainable materials, and collaboration platforms with suppliers. These expenditures facilitate compliance with environmental standards while enhancing efficiency and performance, creating a mutually beneficial situation for enterprises seeking profitability and sustainability.

From a novelty standpoint, this research is one of the few empirical studies examining the junction of GSCM and technology adoption in the agro-processing industry of an emerging economy, specifically Bangladesh. It presents TAGP as a crucial mediating concept and underscores its significance in transforming sustainability objectives into operational results. The work addresses a notable deficiency in current literature by connecting theoretical principles with empirical evidence from a context that has been inadequately examined, despite its vital role in promoting food security, economic development, and environmental sustainability.

6. CONCLUSION AND FUTURE RESEARCH DIRECTION

This study aimed at investigating a critical issue in Bangladesh's agro-processing and food sector, specifically the challenges in efficiently implementing GSCM techniques due to technology constraints. Despite increasing pressure on agro-processing companies to implement environmentally sustainable production practices, many continue to face challenges in converting sustainability aspirations into significant practical results. Green supply chain initiatives, including GP, sustainable packaging, WME, and supplier environmental engagement, are increasingly recognized as vital techniques for addressing environmental issues (Balon, 2020; Feng *et al.*, 2024; Rane & Thakker, 2019). Nonetheless, the insufficient technological infrastructure and limited technology acceptance within the industry have established significant obstacles to fully achieving the advantages of these approaches. The current literature highlights the pivotal impact of TAGP on enhancing resource efficiency, reducing waste, and streamlining operational operations (Hoang *et al.*, 2025). However, there is still insufficient empirical evidence on the role of TAGP as a mediating mechanism between GSCM practices and OP, especially in developing economies like Bangladesh (Ahmed Mustafi *et al.*, 2025).

The study's results offer significant insights into this disparity. The empirical investigation indicated that although GP and WME did not have a direct significant effect on OP, EFP and supplier environmental collaboration exhibited positive and substantial impacts. TAGP significantly mediated all four associations, converting non-significant direct impacts into significant mediated effects for GP and waste management. These results highlight the pivotal role of technology in facilitating the efficacy of green practices and converting them into measurable performance results. The implementation of technology enables companies to address operational inefficiencies and environmental limitations, facilitating the alignment of sustainability objectives with corporate performance indicators. The elevated R-square values for OP and technological adoption further validate the model's robustness, accounting for a significant percentage of variance in the results.

The study's broader ramifications are substantial for both theoretical and practical applications. It theoretically integrates the RBV, NRBV, and the TOE framework, illustrating the impact of internal capabilities and technological readiness on the success of green initiatives in emerging markets. The report underscores the necessity for strategic investments in technology to bolster green activities, especially in sectors such as agro-processing, where operational efficiency and environmental effect are intricately linked. The findings underscore the necessity for governments to cultivate a conducive technological ecosystem and provide incentives for technological adoption among small and medium-sized firms in industry.

Future research can build on these insights by broadening the regional and sectoral dimensions of analysis. Comparative analyses across various locations or sectors would provide a broader comprehension of the function of TAGP in the execution of green supply chains. Furthermore, subsequent research may investigate longitudinal designs to assess the enduring impacts of technological adoption on sustainability and performance indicators. In-depth examinations of technologies, including digital monitoring tools, IoT systems, and waste-to-energy

solutions, would facilitate the identification of innovations that provide the most significant operational and environmental advantages. Investigating the influence of corporate culture, leadership, and external stakeholder pressure as moderators in the TAGP-performance connection may provide refined insights into the internal and external facilitators of green transformation.

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