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RESEARCH PAPER

Manufacturing Ambidexterity and Sustainable Excellence: The Moderated Mediation of Industry 4.0 Readiness in Egypt's Food and Beverage Sector

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ABSTRACT
This study investigates the interplay between manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence in Egypt's food and beverage sector. Using a survey of 308 industry professionals and structural equation modeling (SEM), the study found that Industry 4.0 readiness fully mediates and significantly moderates the relationship between manufacturing ambidexterity and sustainable excellence. Manufacturing ambidexterity alone does not directly impact sustainable excellence, but its effect becomes significant through Industry 4.0 readiness. Sensitivity analysis quantified the results, showing that 43% of the variance in sustainable excellence is explained by the combined influence of ambidexterity and Industry 4.0 readiness. Notably, the fifth hypothesis revealed that Industry 4.0 readiness significantly moderates the impact of manufacturing ambidexterity on sustainable excellence, amplifying its effects at higher readiness levels. This underscores the importance of an organization's preparedness to adopt advanced technologies to enhance the benefits of ambidextrous capabilities. This study emphasizes the importance of digital transformation and ambidextrous strategies for achieving sustainability goals. However, its scope is limited to a single sector in Egypt, suggesting the need for future research in other industries and regions.

KEYWORDS: *Manufacturing ambidexterity; Industry 4.0 readiness; Sustainable excellence; Food and beverage sector.*

1. Introduction

Manufacturing ambidexterity, the ability to simultaneously explore new opportunities and exploit existing capabilities, has become increasingly crucial for sustainable excellence in the food and beverage sector. In Egypt, this concept is particularly relevant as the industry faces challenges in balancing innovation with efficiency to meet growing demands and sustainability goals. The food and beverage sector in Egypt, like many other countries, is grappling with the need to address environmental concerns while maintaining profitability. Green ambidexterity (GA) has emerged as a key strategy for businesses to balance sustainability and profitability [1]. This approach involves developing sustainability-oriented dynamic capabilities that can drive sustainable competitive advantage (SCA) in the industry. In recent years, the Egyptian food and beverage industry has faced numerous challenges, including fluctuating commodity prices, stricter regulation environments, and shifting consumer preferences towards healthier and more sustainable products [2]. These factors necessitate a strategic focus on manufacturing ambidexterity, wherein companies not only optimize their existing operations but also innovate to meet emerging consumer needs. Research indicates that firms that successfully integrate ambidextrous capabilities are better positioned to achieve sustainable excellence, which entails balancing their economic objectives with social and environmental responsibilities [3, 4].

Sustainable excellence in the food and beverage sector goes beyond mere compliance with regulations; it involves adopting practices that not only minimize environmental impact but also enhance social equity and economic viability [5]. For example, companies that embed sustainable sourcing practices into their supply chains, adopt energy-efficient technologies, or invest in

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community engagement initiatives are often recognized as leaders in corporate responsibility and profitability [6]. Moreover, industry 4.0, characterized by the integration of advanced technologies such as the Internet of Things, cyber-physical systems, and cloud computing, is transforming manufacturing processes and business operations [7]. This fourth industrial revolution promises enhanced operational efficiency and sustainable practices, ushering in a new era for businesses [8] (Sharma et al., 2020). In this context, organizational ambidexterity—the ability to balance innovation and exploitation—becomes critical for maintaining competitive advantage [9]. Interestingly, the concept of Industry 4.0 readiness has emerged as a crucial factor for companies, especially SMEs, to assess their preparedness for this technological transition. Various readiness models have been developed, with technology, people, strategy, leadership, process, and innovation identified as the most important dimensions [10]. However, the dominance of the technology dimension (44% of all unique dimensions) suggests that organizations need to focus significantly on improving their technological capabilities to strengthen their Industry 4.0 readiness [10].

Finally, the integration of Industry 4.0 technologies with sustainable development practices is giving rise to the concept of Sustainable Manufacturing 4.0 [11]. This approach aims to balance economic competitiveness with environmental and social sustainability throughout the product lifecycle. As companies strive for operational excellence in this new paradigm, they must consider the impact of Industry 4.0 technologies on sustainability, carefully evaluating each technology's influence on industry-specific sustainability dimensions [12].

Egypt's food and beverage sector faces challenges like fluctuating commodity prices, a shift toward sustainability, and growing regulatory demands [13]. While manufacturing ambidexterity and Industry 4.0 technologies offer solutions, research on their application in developing economies like Egypt is limited [14-17]. Furthermore, the triple bottom line—economic, social, and environmental aspects—remains underexplored, with studies often prioritizing economic outcomes.

The researchers chose to study manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence in Egypt's food and beverage sector due to the industry's unique challenges and critical role in the national economy. The sector faces issues like perishable supply chains, fluctuating commodity prices, and growing demands for sustainable practices. These challenges require firms to balance innovation with operational efficiency while leveraging advanced technologies like IoT and AI. The study focuses on Egypt because most existing research prioritizes developed economies, overlooking the constraints of emerging markets, such as resource scarcity and regulatory pressures. By integrating these constructs, the research aims to provide actionable insights for achieving sustainable excellence in a region with significant economic and sustainability demands. This research aims to address these gaps by exploring how organizations in emerging markets can use ambidexterity and technology to achieve sustainable development goals. this research addresses these questions to contribute to the understanding of how organizations in emerging markets can leverage ambidexterity and technological advancements to achieve sustainable development goals.

RQ1. How does manufacturing ambidexterity influence the attainment of sustainable excellence in Egypt's food and beverage sector?

RQ2. What role does Industry 4.0 readiness play in mediating the relationship between manufacturing ambidexterity and sustainable excellence?

RQ3. How can organizations balance exploration and exploitation to enhance their performance across economic, social, environmental, and innovation dimensions?

RQ4. What specific challenges and opportunities do Industry 4.0 technologies present for sustainable excellence in Egypt's food and beverage industry?

The research aims to explore the interplay between manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence within Egypt's food and beverage sector. Specifically, it investigates how the balance of exploitative and exploratory manufacturing strategies influences the sector's ability to integrate advanced technologies for improved economic, social, and environmental outcomes.

By focusing on this sector in Egypt, the study seeks to contextualize these global concepts within a region characterized by unique challenges such as resource scarcity, regulatory pressures, and economic constraints. Ultimately, the research intends to provide a framework

for achieving sustainable excellence through ambidexterity and technological readiness.

2. Literature Review, Research Hypotheses, Gap, and Framework

2.1. Manufacturing ambidexterity

Manufacturing ambidexterity refers to the capability of manufacturing firms to simultaneously pursue both exploration (radical innovation) and exploitation (incremental innovation) activities. This concept is rooted in organizational ambidexterity, which emphasizes the need for businesses to balance operational efficiency with flexibility to thrive in competitive markets [18]. In the manufacturing context, ambidexterity enables companies to maintain daily excellence in operations while constantly seeking innovation [19], the concept of manufacturing ambidexterity extends beyond just balancing innovation types. It also encompasses the ability to manage trade-offs between efficiency and flexibility in manufacturing strategies; It enables manufacturers to adapt to changing market conditions while maintaining operational excellence [20].

2.2. Industry 4.0 readiness

Industry 4.0 readiness refers to the level of preparedness and capability of an organization to integrate and implement digital technologies, processes, and practices associated with the fourth industrial revolution. It encompasses the assessment of a company's current status in terms of its ability to adopt and leverage Industry 4.0 concepts and technologies [21, 22].

2.3. Sustainable excellence

Sustainable excellence refers to an organization's ability to consistently achieve outstanding performance across multiple dimensions while ensuring long-term viability and a positive impact on society and the environment [23]. This concept integrates the principles of operational excellence with sustainability, emphasizing the need for organizations to excel in their core functions while also addressing social, economic, and environmental concerns [24].

2.4. Manufacturing ambidexterity and industry 4.0 readiness

Manufacturing ambidexterity, which involves balancing the exploitation of existing capabilities with the exploration of new opportunities, is closely linked to Industry 4.0 readiness. In the context of Egypt's food and beverage sector, manufacturing ambidexterity and Industry 4.0 readiness are crucial factors for competitiveness and sustainable growth. Manufacturing ambidexterity, which involves balancing technological and relational social capital factors between buyers and suppliers, can lead to enhanced digital manufacturing capabilities and innovation potential [25]. This approach is particularly relevant for the food and beverage industry, as it can help companies adapt to the flexible and individualized manufacturing processes proposed by Industry 4.0 [26]. However, assessing Industry 4.0 readiness is essential for successful implementation, especially for small and medium-sized enterprises (SMEs) that form a significant part of the sector [27, 21].

Moreover, while Industry 4.0 offers numerous advantages such as automated tasks, cost reduction, and resource efficiency [28], it also presents challenges, particularly for smaller companies with limited capital and technological expertise. The food and beverage sector in Egypt may face similar constraints, necessitating a careful assessment of readiness and strategic implementation of Industry 4.0 technologies [29, 30]. To address these challenges, a holistic approach to Industry 4.0 readiness assessment, considering dimensions such as organizational resilience, infrastructure systems, manufacturing systems, data transformation, and digital technology, could be beneficial for Egypt's food and beverage sector [27, 31].

Interestingly, while technology is a crucial aspect of Industry 4.0 readiness, it is not the sole focus. Assessing Industry 4.0 readiness through comprehensive models [32] and fostering ambidexterity through the development of intellectual capital and technology absorptive capacity [9] are crucial steps for manufacturing organizations aiming to thrive in the era of Industry 4.0. By focusing on these aspects, manufacturers can enhance their readiness for Industry 4.0 while maintaining the flexibility to exploit existing strengths and explore new opportunities. Therefore, the following hypothesis can be proposed:

Hypothesis 1. Manufacturing ambidexterity has a positive effect on Industry 4.0 readiness.

2.5. Industry 4.0 readiness and sustainable excellence

The integration of advanced technologies and

practices associated with Industry 4.0 contributes to improved sustainability and operational excellence in manufacturing and supply chains. Research indicates that Industry 4.0 adoption positively influences sustainable and circular practices in supply chains [33]. The study reveals a strong link between Industry 4.0 implementation and the promotion of circular and sustainable approaches, particularly in the textile sector. Similarly, lean 4.0 practices, which combine traditional lean thinking with Internet-enabled Industry 4.0 technologies, have been found to enhance operational readiness and technological readiness, contributing to a sustainable manufacturing supply chain [30]. In addition, the adoption of Industry 4.0 practices can lead to sustainable operations and operational excellence, as evidenced by the structural equation modeling study [34]. Further, to improve their Industry 4.0 readiness and achieve sustainable excellence, companies should focus on developing their information system infrastructure, investing in Internet stability, and promoting circular economy awareness [35, 36]. Therefore, the following hypothesis can be proposed:

Hypothesis 2. Industry 4.0 readiness has a positive effect on sustainable excellence.

2.6. Manufacturing ambidexterity and sustainable excellence

Manufacturing ambidexterity, which involves balancing exploitative and exploratory innovation activities, plays a crucial role in achieving sustainable excellence in the industry. This approach enables organizations to simultaneously improve existing processes and explore new opportunities, leading to enhanced sustainability performance across environmental, social, and economic dimensions [37]. Also, organizational ambidexterity allows businesses to innovate while maintaining operational efficiency, driving their transition to sustainable practices [38], Knowledge sharing and employee ambidexterity have positively impacted sustainable performance in manufacturing firms [39], Through fostering exploration (e.g., development of circular product designs) and exploitation (e.g., operational efficiency in material use), ambidexterity enhances an organization's ability to meet the triple bottom line of sustainability—environmental, social, and economic performance [40], quality management ambidexterity, which combines quality exploration and exploitation practices, has been identified as an important determinant of environmentally sustainable production [16]. Interestingly, the relationship between sustainability and innovation performance is not always straightforward. Studies suggest that an optimal level of ambidexterity leads to more sustainable innovation processes. For instance, in the IT hardware industry, companies can improve the sustainability of their R&D processes by managing ambidexterity levels and adopting open innovation strategies for exploration processes [41].

Additionally, Green ambidexterity enhances sustainable competitive advantage (SCA) by aligning environmental goals with economic performance, attracting eco-conscious consumers, and meeting regulations. Exploration drives sustainability innovation, like eco-friendly products and alternative energy, while exploitation improves efficiency, reduces waste, and refines green practices [1]. Organizations with high absorptive capacity can innovate incrementally for operational improvements and radically for long-term adaptability [42]. This balance of exploration and exploitation fosters sustainable practices, particularly in supply chains, improving environmental, economic, and social performance [43]. Finally, the food and beverage sector in Egypt faces unique challenges, such as fluctuating supply chains and regulatory pressures, necessitating a flexible and responsive manufacturing approach. Companies that embrace manufacturing ambidexterity can swiftly adapt to these challenges, ensuring compliance with sustainability standards while meeting market demands. Therefore, the following hypothesis can be proposed:

Hypothesis 3. Manufacturing ambidexterity has a positive effect on sustainable excellence.

2.7. Mediating role of industry 4.0 readiness

Industry 4.0 readiness can play a crucial mediating role in the relationship between manufacturing ambidexterity and sustainable excellence. Industry 4.0 readiness acts as a full mediator between strategic orientations and sustainable competitive advantage, highlighting its importance in the digital transformation process [35]. The adoption of Industry 4.0 practices, such as advanced robotics, smart logistics, and virtual reality, enables SMEs to achieve sustainability in manufacturing operations and attain operational excellence with greater efficiency and productivity [34]. This suggests that Industry 4.0 readiness acts as a

catalyst for translating ambidextrous capabilities into sustainable performance outcomes.

Interestingly, the relationship between Industry 4.0 and sustainable performance is not always direct. Studies have found that organizational ambidexterity and digital business transformation can mediate this relationship by integrating circular principles to devise new sustainable business models [44]. Additionally, knowledge sharing and employee ambidexterity have been shown to positively influence sustainable performance in manufacturing firms [39]. Therefore, the following hypothesis can be proposed:

Hypothesis 4. Industry 4.0 readiness acts as a mediator between manufacturing ambidexterity and sustainable excellence.

2.8. Moderating role of industry 4.0 readiness

Industry 4.0 readiness can play a significant moderating role in the relationship between manufacturing ambidexterity and sustainable excellence. Research indicates that the adoption of Industry 4.0 technologies positively influences sustainable performance and operational excellence in manufacturing organizations [45, 34]. Interestingly, the implementation of Industry 4.0 technologies can enhance Manufacturing ambidexterity. The adoption of blockchain technology, for instance, has been found to positively affect both the exploration and exploitation of innovation management in buyer-supplier relationships [25]. This suggests that Industry 4.0 technologies can facilitate the balance between innovation and efficiency in manufacturing processes.

Interestingly, the implementation of Industry 4.0 technologies can enhance relationships between an organization's ambidexterity and sustainable excellence. The adoption of blockchain technology, for instance, has been found to positively affect both the exploration and exploitation of innovation management in buyer-supplier relationships [25]. This suggests that Industry 4.0 technologies can facilitate the balance between innovation and efficiency in manufacturing processes. In addition, Industry 4.0 readiness and manufacturing ambidexterity are interconnected concepts that contribute to an organization's ability to navigate the sustainable excellence landscape. Assessing Industry 4.0 readiness through comprehensive models [32] and fostering ambidexterity through the development of intellectual capital and technology absorptive capacity [9] are crucial steps for manufacturing organizations aiming to thrive in the era of Industry 4.0. By focusing on these aspects, companies can enhance their competitiveness and successfully implement sustainable excellence initiatives. Therefore, the following hypothesis can be proposed:

Hypothesis 5. Industry 4.0 readiness acts as a moderator between manufacturing ambidexterity and sustainable excellence.

2.9. Research gap

The research on manufacturing ambidexterity and sustainable excellence in Egypt's food and beverage sector presents several gaps that require further exploration. Firstly, there is a lack of studies contextualized to Egypt, as most existing research focuses on developed economies or broader global contexts. This neglects the specific challenges such as resource scarcity, regulatory pressures, and economic constraints unique to the Egyptian context [14, 15]. Additionally, the food and beverage sector itself, characterized by high perishability, supply chain complexities, and significant sustainability demands, remains underrepresented in research on ambidexterity [16]. Another gap lies in the limited exploration of the triple bottom line—economic, social, and environmental dimensions. Current studies prioritize economic performance, leaving the social and environmental impacts of ambidextrous practices underexplored [17]. The integration of Industry 4.0 technologies such as IoT and AI into ambidextrous manufacturing practices for sustainability also remains under-researched, despite its potential to transform efficiency and innovation in the sector [46].

2.10. Contribution and novelty

This study makes significant contributions to the literature and provides novel insights in multiple ways:

- Contextual Contribution: By focusing on Egypt's food and beverage sector, this research addresses the unique challenges of an emerging economy, including resource constraints and complex regulatory requirements, thus filling a geographical and sectoral research gap.
- Integration of Concepts: The study uniquely combines manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence,

offering a multidimensional framework that explores both mediating and moderating mechanisms.

- Expanded Sustainability Framework: Unlike most existing studies, this research examines sustainable excellence through four key dimensions—environmental performance, social performance, operational performance, and innovation performance—providing a comprehensive perspective on sustainability outcomes.
- Novel Empirical Insights: Using advanced structural equation modeling (SEM), the research reveals how Industry 4.0 readiness acts as both a full mediator and significant moderator, quantifying its impact on sustainable outcomes with precision (explaining 43% of variance).
- Emerging Market Application of Industry 4.0: By examining how Industry 4.0 readiness enhances the effectiveness of ambidextrous strategies in a resource-scarce context, the study offers actionable insights for emerging markets, paving the way for future research and policy recommendations.

In summary, this study provides a foundational framework for understanding how organizations in developing economies can leverage manufacturing ambidexterity and technological readiness to achieve sustainable excellence across all four dimensions of sustainability.

2.11. Framework

To address this research problem, a theoretical framework combining ambidexterity, industry 4.0 readiness, and sustainability will be applied. Drawing from ambidexterity literature in manufacturing, it will explore sustainability in the food and beverage sector. The dynamic capabilities framework may explain how firms reconfigure resources to balance exploiting existing capabilities and exploring new opportunities, fostering innovation ambidexterity and improving sustainable excellence [37, 17]. Manufacturing ambidexterity is the ability of organizations to balance innovation (exploration) and efficiency (exploitation), enabling adaptation to market changes while achieving sustainability goals. Industry 4.0 readiness, reflecting an organization's preparedness to adopt technologies like IoT and AI, serves as a critical enabler by mediating and moderating the relationship between ambidexterity and sustainable excellence. Sustainable excellence involves achieving exceptional performance across environmental, social, operational, and innovation dimensions, aligning sustainability with profitability and innovation. Manufacturing ambidexterity alone may not directly lead to sustainable excellence; Industry 4.0 readiness acts as a bridge and amplifies its impact. The integration of these constructs creates a framework for operational efficiency, waste reduction, traceability, and innovation, critical for competitive and sustainable success in dynamic, resource-constrained markets like Egypt.

3. Methodology

3.1. Measurement

To analyze the hypothesized relationships, a questionnaire was designed to measure three main variables: manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence. Scales were adapted from prior studies, with manufacturing ambidexterity measured as a second-order construct using exploration and exploitation scales [47], sustainable excellence measured across four dimensions [48], and Industry 4.0 readiness using seven items [49].

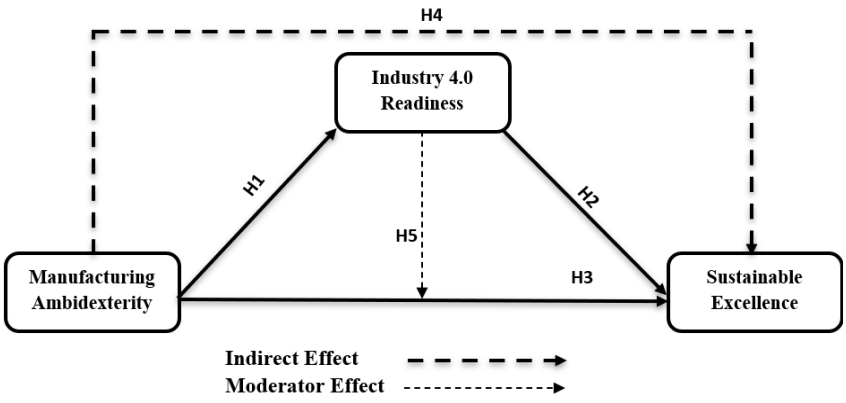

Fig.1. Research framework

The survey, written in Arabic to ensure clarity, was pre-tested for comprehension, resulting in minor adjustments but no major issues.

3.2. Data collection and sample

Data were collected via online and offline surveys targeting food and beverage industry professionals in Egypt, chosen for the sector's economic significance and challenges in sustainability and supply chain management under strict regulations. Respondents were senior managers, operations executives, supervisors, and technology specialists familiar with strategic practices and Industry 4.0 technologies. Of 354 distributed questionnaires, 308 valid responses were analyzed (77% response rate), with 46 excluded due to missing values, straight-line responses, and outliers. Sample demographics are detailed in Table 1. Table 1 reveals that the sample primarily consisted of males, with most respondents aged 30–40 years. Participants with a bachelor's degree were the most engaged, and the majority reported a monthly income of 30,000–60,000 Egyptian pounds. Most respondents held department manager positions.

4. Data Analysis and Results

4.1. Evaluating the reflective measurement model

The model included second-order factors for manufacturing ambidexterity and sustainable excellence, with the reflective measurement model assessed at both levels. First-order evaluation focused on indicator consistency, reliability, convergent validity, and discriminant validity (Figure 2). Table 2 presents factor loadings for three variables—manufacturing ambidexterity (exploration and exploitation), Industry 4.0 readiness, and sustainable excellence (environmental, social, operational, and innovation performance)—and their sub-variables.

According to [50], all research indicators met the factor loading threshold of 0.708, ranging from 0.781 to 0.912, confirming reliability. Cronbach's alpha values (0.811–0.938) and CR estimates (0.876–0.953) exceeded 0.70, ensuring internal consistency, while AVE values (0.638–0.801) surpassed 0.50, confirming convergent validity.

Tables 3 and 4 confirm discriminant validity, as the square root of the AVE for each construct exceeded its pairwise correlations [51], and all HTMT values were below the 0.85 threshold [52]. The second-order constructs were initially excluded from the model. A two-stage approach was applied to assess the second-order reflective measurement model for manufacturing ambidexterity and sustainable excellence [53] (Figure 3).

Tab.1. Sample description

Variable	Classification	Frequency	Percentage (%)
Gender	Male	242	79
	Female	66	21
	Total	**308**	**100.0**
Age	Under 30 Years	27	9
	Between 30 and 40 years	108	35
	Between 40 and 50 years	92	30
	Between 50 and 60 years	63	20
	Above 60 years	18	6
	Total	**308**	**100.0**
Educational Level	Bachelor's degree	261	85
	Master degree	38	12
	PhD	9	3
	Total	**308**	**100.0**
Income	Less than 10000 EP	19	6
	From 10000 to 30000 EP	116	38
	From 30001 to 60000 EP	138	45
	More than 60000 EP	35	11
	Total	**308**	**100.0**
position	Senior Manager	33	11
	Department Manager	96	31
	Supervisor	87	28
	Technical Officer	92	30
	Total	**308**	**100.0**

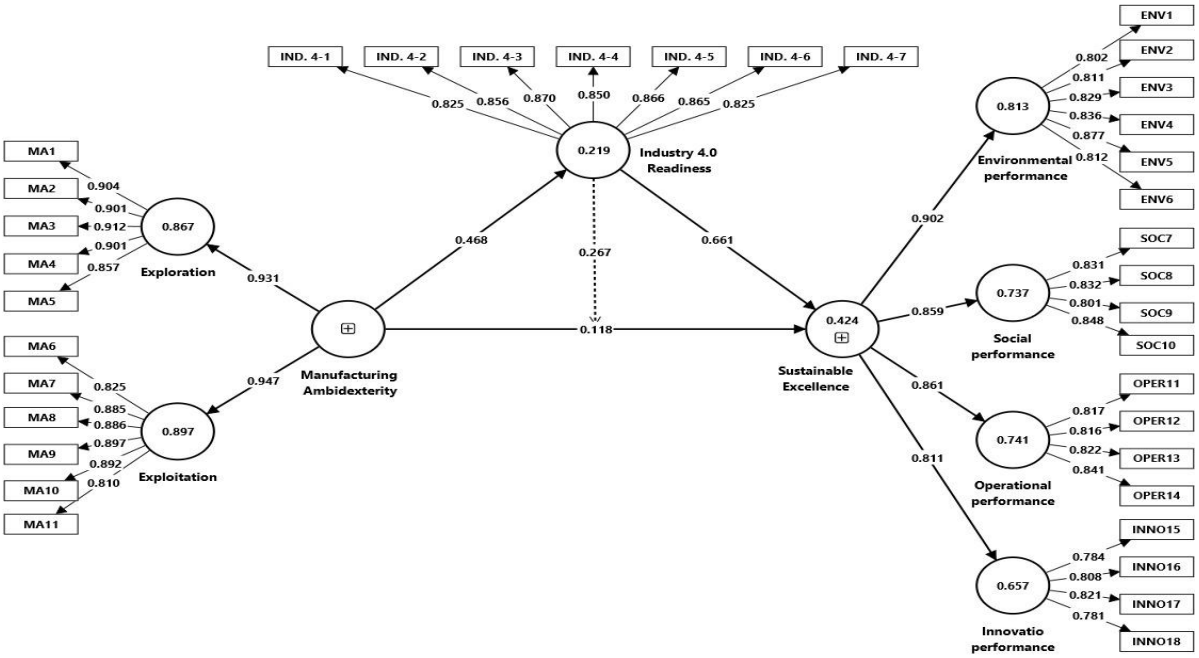

Fig.2. The reflective measurement model (First-order)

Tab.2. Measurement items of the first-order constructs

Construct and Items	Standardized Loading (sig.)	Alpha	CR	AVE
Manufacturing Ambidexterity				
Exploration		**0.938**	**0.953**	**0.801**
MA1: Our activities search for new possibilities with respect to products/services, processes or markets.	0.904**			
MA2: Our activities try to evaluate diverse options with respect to products/services, processes or markets.	0.901**			
MA3: Our activities are focused on strong renewal of products/ services or processes.	0.912**			
MA4: Our activities require quite some adaptability of ourselves.	0.901**			
MA5: Our activities require you to learn new skills or knowledge.	0.857**			
Exploitation		**0.933**	**0.947**	**0.751**
MA6: We develop activities in which a lot of experience has been accumulated by yourself.	0.825**			
MA7: We develop activities that serve existing (internal) customers with existing services/products.	0.885**			
MA8: We develop activities of which it is clear to us how to conduct them	0.886**			
MA9: We develop activities primarily focused on achieving short-term goals.	0.897**			
MA10: We develop activities that we can properly conduct by using our present knowledge.	0.892**			
MA11: We develop activities that fit into existing company policy.	0.810**			
Industry 4.0 Readiness		**0.937**	**0.948**	**0.742**
IND. 4-1: We experience pressure to work with the new digital technologies.	0.825**			
IND. 4-2: We have the willingness to take risks to experiment with the new digital technologies.	0.856**			
IND. 4-3: We have the necessary knowledge about the new digital technologies to judge their importance for our company.	0.870**			
IND. 4-4: We have the necessary support from top management	0.850**			

to judge and work with the new digital technologies.				
IND. 4-5: Our employees have the right competencies to work with the new digital technologies.	0.866**			
IND. 4-6: Our employees have the right motivation to judge and work with the new digital technologies.	0.865**			
IND. 4-7: We have the economic freedom to work with the new digital technologies.	0.825**			
Sustainable Excellence				
Environmental performance		**0.908**	**0.929**	**0.686**
ENV1: Reduction of air emission.	0.802**			
ENV2: Reduction of waste water.	0.811**			
ENV3: Reduction of solid wastes.	0.829**			
ENV4: Decrease of consumption of hazardous/harmful/toxic materials.	0.836**			
ENV5: Decrease in frequency of environmental accidents.	0.877**			
ENV6: Improve an enterprise's environmental situation.	0.812**			
Social performance		**0.847**	**0.897**	**0.686**
SOC7: In general, our employees are satisfied with their jobs.	0.831**			
SOC 8 The amount of stress at work has decreased over the last three years.	0.832**			
SOC9: Health and safety incidents have decreased over the last three years.	0.801**			
SOC10: Injuries and lost days related to injuries have decreased over the last three years.	0.848**			
Operational performance		**0.842**	**0.894**	**0.679**
OPER11: Production cost.	0.817**			
OPER12: Labor productivity.	0.816**			
OPER13: High product performance.	0.822**			
OPER14: Ease (cost and time) to service product (well-designed product for an effective service).	0.841**			
Innovation performance		**0.811**	**0.876**	**0.638**
INNO15: Novelty of new products/ services.	0.784**			
INNO16: Number of new products/ services.	0.808**			
INNO17: Speed of product/services development.	0.821**			
INNO18: Technological competitiveness Early adoption of new technology.	0.781**			
Note: **: P< 0.01. **Alpha** denotes Cronbach's alpha; **CR** denotes composite reliability; and **AVE** is the average variance extracted.				

Tab.3. Descriptive statistics and correlations between constructs (Fornell-Larcker method)

NO.	Construct	1	2	3	4	5	6	7
1	Exploration	***0.895*****						
2	Exploitation	0.765**	***0.866*****					
3	Industry 4.0 Readiness	0.421**	0.455**	***0.851*****				
4	Environmental performance	0.249**	0.213**	0.499**	***0.828*****			
5	Social performance	0.264**	0.256**	0.529**	0.692**	***0.828*****		
6	Operational performance	0.217**	0.218**	0.493**	0.684**	0.668**	***0.824*****	
7	Innovation performance	0.236**	0.251**	0.572**	0.611**	0.618**	0.647**	***0.799*****
	Mean	4.195	4.038	4.117	4..053	3.747	4.038	4.028
	Standard Deviation	0.784	0.806	0.753	0.815	0.923	0.981	0.866
Notes: **: P< 001; The square root of AVE is typed in **bold italic** along the diagonal.								

After the first-order evaluation, the scores of the latent variables were determined and used as manifest variables for the second-order construct. Tables 5 and 6 Shows the validity and reliability results for these constructs, starting with Table 5, which shows the indicators factor loading, which ranged between 0.843 and 0.942.

Tab.4. Heterotrait-monotrait (HTMT) criterion values

NO.	Construct	1	2	3	4	5	6	7
1	Exploration							
2	Exploitation	0.817						
3	Industry 4.0 Readiness	0.446	0.482					
4	Environmental performance	0.268	0.228	0.534				
5	Social performance	0.294	0.284	0.590	0.788			
6	Operational performance	0.243	0.243	0.551	0.781	0.791		
7	Innovation performance	0.269	0.286	0.630	0.710	0.745	0.782	0.839

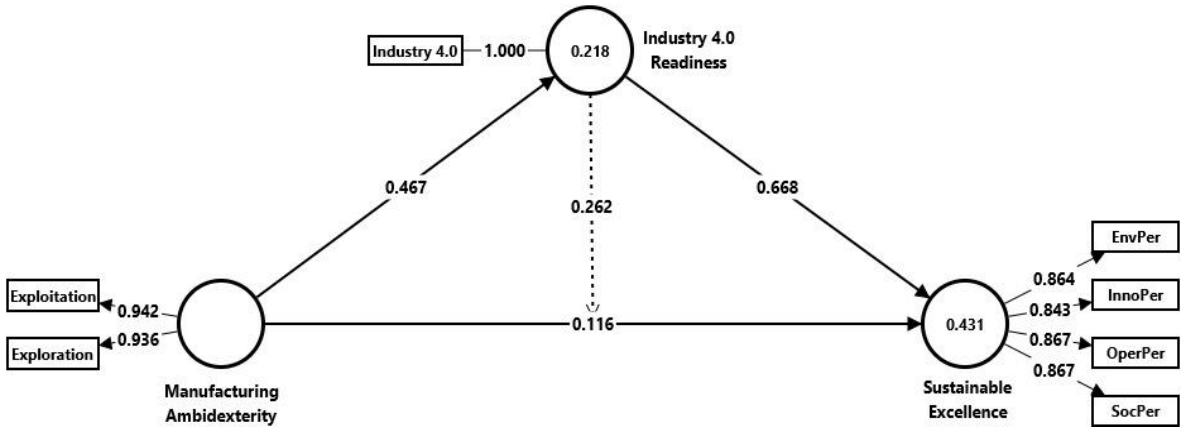

Fig.3. The reflective measurement model (Second-order)

Tab.5. Measurement items of the second-order constructs

Construct and Items	Standardized Loading (sig.)	Cronbach's Alpha	CR	AVE
Manufacturing Ambidexterity		0.867	0.938	0.882
Exploration	0.942			
Exploitation	0.936			
Sustainable Excellence		0.883	0.919	0.740
Environmental performance	0.864			
Social performance	0.843			
Operational performance	0.867			
Innovation performance	0.867			

Note: **: P< 0.01. **Alpha** denotes Cronbach's alpha; **CR** denotes composite reliability; and **AVE** is the average variance extracted.

Tab.6. Heterotrait-monotrait (HTMT) criterion values (second-order)

NO.	Construct	1	2	3
1	Manufacturing Ambidexterity			
2	Industry 4.0 Readiness	0.501		
3	Sustainable Excellence	0.336	0.641	

Cronbach's alpha values were 0.867 for manufacturing ambidexterity and 0.883 for sustainable excellence, with composite reliability (CR) at 0.938 and 0.919, respectively, and AVE values exceeding 0.50, confirming internal consistency and convergent validity. As shown in Table 6, HTMT values were below 0.85, establishing discriminant validity for second-order constructs. These results confirm acceptable psychometric properties.

4.2. Evaluating the structural model

The structural model (Figure 4) was evaluated using the variance inflation factor (VIF), effect size (f^2), and coefficient of determination (R^2). Results are presented in Table 7.

The structural model was evaluated using variance inflation factor (VIF), with all values below the threshold of 3, confirming no collinearity issues [50].

Tab.7. Structural model evaluation

Construct	Variance Inflation Factor (VIF) Collinearity Assessment	Confidence Intervals 95% (BCa) Bootstrap		F^2 Effect Size	Level of R^2
		2.5%	97%		
Manufacturing Ambidexterity	1.000	0.361	0.562	0.278	———
	1.429	- 0.034	0.264	0.017	———
Manufacturing Ambidexterity × Industry 4.0 Readiness	1.329	0.101	0.390	0.117	———
Industry 4.0 Readiness	1.357	0.562	0.774	0.577	0.218
Sustainable Excellence					0.431

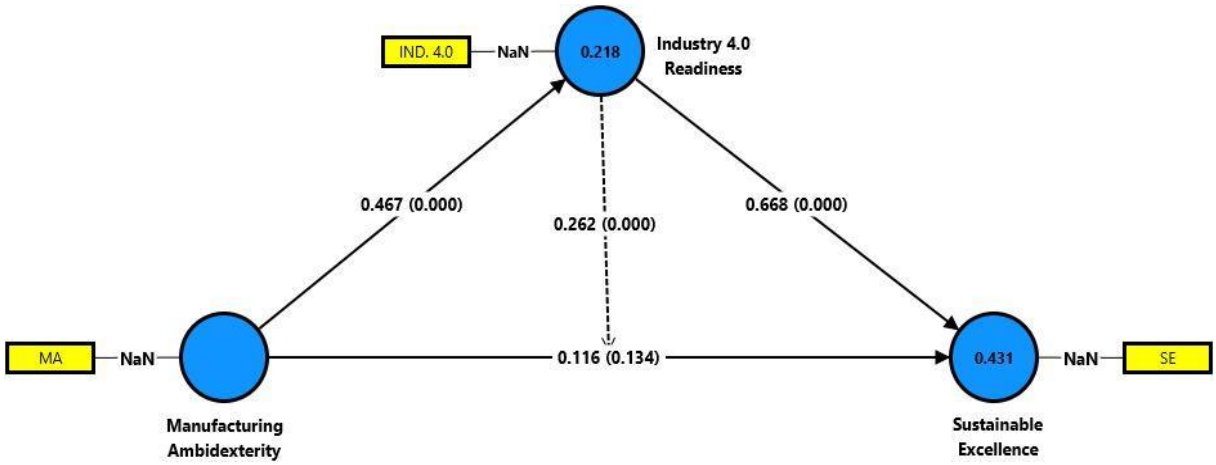

Fig.4. The structural model

Effect sizes (f^2) for the constructs were 0.278, 0.017, 0.117, and 0.577, ranging from weak to strong [54]. The coefficient of determination (R^2) showed that 21.8% of Industry 4.0 readiness (R^2= 0.218) was explained by manufacturing ambidexterity, while 43% of sustainable excellence (R^2= 0.431) was explained by manufacturing ambidexterity and its interaction with Industry 4.0 readiness. No collinearity issues were identified in the structural model [55].

4.3. Hypotheses tests

The "direct effect" hypotheses were tested using standardized path (beta) coefficients and bootstrapping with 5,000 resamples. As shown in Table 8, manufacturing ambidexterity positively influenced Industry 4.0 readiness (H1: β= 0.467, p< 0.01, CI= 0.361–0.562), supporting H1.

Industry 4.0 readiness positively impacted sustainable excellence (H2: β= 0.668, p< 0.01, CI= 0.562–0.774), confirming H2. However, no significant direct effect of manufacturing ambidexterity on sustainable excellence was found (H3: β= 0.116, p= 0.134, CI= -0.034–0.264), rejecting H3.

The mediating role of Industry 4.0 readiness (H4) was tested using the BCa bootstrap method with 95% confidence intervals.

Tab.8. Structural model estimates

Hypothesis		β	Critical ratio	P-Value	Results
H1	Manufacturing Ambidexterity → Industry 4.0 Readiness	0.467	9.165	<0.01	Supported
H2	Industry 4.0 Readiness → Sustainable Excellence	0.668	12.536	<0.01	Supported
H3	Manufacturing Ambidexterity → Sustainable Excellence	0.116	1.500	=0.134	Unsupported
H4	Manufacturing Ambidexterity → Industry 4.0 Readiness Sustainable Excellence	0.312	6.944	<0.01	Full mediated
H5	Manufacturing Ambidexterity x Industry 4.0 Readiness → Sustainable Excellence	0.262	3.578	<0.01	Moderated

Results showed a significant indirect effect of manufacturing ambidexterity on sustainable excellence through Industry 4.0 readiness ($\beta = 0.312$, $p < 0.01$, CI = 0.243–0.461), confirming full mediation due to the insignificant direct effect (H3). Additionally, the moderating role (H5) revealed a significant interaction effect ($\beta = 0.262$, $p < 0.01$, CI = 0.158–0.374), indicating that higher Industry 4.0 readiness strengthens the positive impact of manufacturing ambidexterity on sustainable excellence. Results are summarized in Table 8.

5. Discussions

This study examined the relationships between manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence in Egypt's food and beverage sector, focusing on both the mediating and moderating roles of Industry 4.0 readiness. The findings highlight the critical importance of Industry 4.0 readiness in amplifying the impact of manufacturing ambidexterity on achieving sustainable excellence. The results support H1, indicating that manufacturing ambidexterity positively impacts Industry 4.0 readiness. The evidence underscores that manufacturing ambidexterity—balancing the exploitation of existing resources and the exploration of new opportunities—enables organizations to better prepare for and implement Industry 4.0 technologies. This effect is achieved through enhanced innovation potential and the development of critical digital manufacturing capabilities. This result aligns with [25], who argue that integrating internal processes and relational networks enhances digital manufacturing and innovation by fostering collaboration and trust among supply chain stakeholders, supporting Industry 4.0 sustainability and efficiency goals. Similarly, [31] highlights that ambidextrous organizations adapt better to Industry 4.0 challenges through strategic flexibility and resource optimization. This readiness is reflected in enhanced technological integration, operational efficiency, and competitive advantage, as demonstrated by models assessing maturity levels across strategic, cultural, and technological dimensions. These results further emphasize the importance of ambidexterity for companies aiming to achieve competitive advantage in the era of Industry 4.0.

Furthermore, the results support H2, which indicates that Industry 4.0 readiness significantly impacts sustainable excellence in manufacturing and supply chain operations. This result aligns with the argument in [33] that Industry 4.0 technologies promote circular and sustainable practices, particularly in resource-intensive sectors such as textiles, by facilitating the adoption of efficient, eco-friendly processes. Furthermore, these results are also in line with those of [30], who states that the integration of Lean 4.0 practices enhances operational and technological readiness, contributing to more sustainable supply chains by combining traditional efficiency methods with advanced Industry 4.0 tools. Consistent with these findings, [34] argues that Industry 4.0 readiness supports sustainable operations and operational excellence through better resource utilization and process optimization. Additionally, this result aligns with [35] and [36], who argue that improvements in information system infrastructure, Internet reliability, and circular economy awareness are identified as critical enablers for organizations aiming to enhance their Industry 4.0 readiness and achieve sustainable excellence. These findings reinforce the notion that Industry 4.0 readiness catalyzes sustainability-driven transformations in manufacturing and supply chains.

Moreover, the findings for H3 indicate that manufacturing ambidexterity does not have a direct effect on sustainable excellence within the studied model. This result suggests that the relationship may be contingent upon other mediating or moderating variables, such as Industry 4.0 readiness or organizational capabilities, which were not directly examined in isolation in this context. Previous studies have demonstrated that manufacturing ambidexterity can significantly influence sustainability outcomes when paired with enablers like circular economy practices, green ambidexterity, or absorptive capacity [1, 38, 42]. For instance, ambidextrous organizations often achieve sustainable excellence by balancing exploitative improvements, such as operational efficiency, with explorative innovations, like eco-friendly product designs [16, 40]. However, the lack of a direct relationship in this study may point to the importance of contextual or sector-specific factors, such as the challenges faced by Egypt's food and beverage sector, including regulatory pressures and fluctuating supply chains. These findings highlight the need

to explore interaction effects and broader frameworks, suggesting that ambidexterity alone is insufficient without the integration of supporting capabilities, such as technological readiness or knowledge sharing, to drive sustainable excellence [39, 41].

Likewise, the findings for Hypothesis 4 confirm that Industry 4.0 readiness fully mediates the relationship between manufacturing ambidexterity and sustainable excellence, emphasizing its pivotal role in enabling ambidextrous capabilities to translate into sustainable performance outcomes. This result aligns with [34] that highlights Industry 4.0 readiness as a critical enabler for digital transformation, fostering operational excellence, and enhancing efficiency and productivity in manufacturing through technologies such as advanced robotics, smart logistics, and virtual reality. Furthermore, these findings align with the argument in the study by [35] that the mediating role of Industry 4.0 readiness reflects its capacity to integrate ambidextrous exploration and exploitation strategies with sustainability goals as it bridges technological adoption and environmental, social, and economic performance. Additionally, similar findings in the literature [39] show that knowledge sharing and employee ambidexterity enhance the effects of Industry 4.0 practices, further linking organizational ingenuity to sustainable excellence. This evidence underscores the importance of investing in Industry 4.0 readiness as a catalyst for leveraging ambidextrous capabilities to achieve sustainability and competitive advantage.

Finally, the findings for H5 confirm that Industry 4.0 readiness significantly moderates the relationship between manufacturing ambidexterity and sustainable excellence, amplifying the impact of ambidextrous capabilities on sustainability outcomes. This supports the notion that higher levels of Industry 4.0 readiness enhance an organization’s ability to balance exploration and exploitation, thereby improving environmental, social, and economic performance. reveal that Industry 4.0 readiness significantly moderates the relationship between manufacturing ambidexterity and sustainable excellence, amplifying the positive effects of ambidextrous capabilities on sustainability outcomes. This indicates that organizations with higher levels of readiness for adopting advanced technologies, such as IoT, AI, and blockchain, are better equipped to balance exploration (innovation) and exploitation (efficiency), ultimately enhancing performance across environmental, social, operational, and innovation dimensions. The findings underscore the transformative role of digital readiness in enabling firms to maximize the impact of ambidextrous strategies, particularly in dynamic and resource-constrained contexts like Egypt's food and beverage sector. This highlights the need for investments in technological infrastructure and capacity building to leverage the synergistic benefits of ambidexterity and Industry 4.0 readiness for achieving sustainable excellence.

These findings align with the study by [25] which shows the moderating role of Industry 4.0 readiness is evident in its ability to facilitate advanced technological integration, such as blockchain, which promotes innovation and operational efficiency in buyer-supplier relationships by optimizing ambidextrous innovation management. Additionally, these results are also in line with those of [9] who state that when Industry 4.0 readiness complements manufacturing ambidexterity by fostering intellectual capital development and technology absorptive capacity, it enables organizations to navigate the complexities of sustainable excellence in dynamic markets. Consistent with these findings, [32] argues that the comprehensive readiness models also provide organizations with structured frameworks to exploit new technologies effectively, highlighting the synergistic role of Industry 4.0 readiness and ambidexterity in driving sustainability initiatives. These findings underscore the importance of investing in Industry 4.0 readiness as a strategic enabler that not only enhances the efficacy of manufacturing ambidexterity but also bolsters overall organizational competitiveness and sustainability.

6. Conclusion

This study highlights the critical interplay between manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence in Egypt's food and beverage sector. The findings reveal that while manufacturing ambidexterity alone does not directly impact sustainable excellence, its effects become significant through the mediating and moderating roles of Industry 4.0 readiness. Industry 4.0 readiness emerges as a transformative enabler, bridging the gap between

ambidextrous capabilities and sustainability outcomes by fostering the adoption of advanced technologies and enhancing operational efficiency [25, 34]. The mediating role of Industry 4.0 readiness underscores its importance as a catalyst for translating ambidextrous exploration and exploitation strategies into tangible sustainability achievements. This highlights the need for organizations to focus on building digital infrastructure, fostering innovation, and integrating Industry 4.0 technologies to achieve excellence across environmental, social, and economic dimensions [35]. Additionally, the moderating role of Industry 4.0 readiness demonstrates its capacity to amplify the positive effects of ambidexterity, enabling organizations to adapt and thrive in dynamic and competitive markets [45].

6.1. Theoretical contribution

This study advances the understanding of manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence. It reveals that ambidexterity indirectly impacts sustainable excellence, emphasizing Industry 4.0 readiness as a key mediator and moderator. By uncovering how ambidextrous capabilities drive environmental, social, and economic sustainability, this research offers new insights into achieving the triple bottom line. This research enhances the understanding of Industry 4.0 readiness as both a mediator and moderator in sustainability frameworks. It shows how Industry 4.0 readiness supports advanced technology adoption and strengthens ambidextrous strategies, enabling organizations to effectively manage sustainability in dynamic environments. This study enhances research on sustainable excellence by examining Industry 4.0 readiness and ambidexterity in Egypt's food and beverage sector. This research combines organizational theory, technology adoption models, and sustainability frameworks to offer a multidimensional view of sustainable excellence. It highlights the role of dynamic capabilities, like technological absorptive capacity, in leveraging Industry 4.0 technologies, emphasizing the interdependence of innovation, ambidexterity, and digital readiness for sustainable outcomes.

6.2. Practical contribution

This study offers practical insights for managers, policymakers, and practitioners in emerging markets like Egypt's food and beverage industry. It highlights the role of integrating manufacturing ambidexterity with Industry 4.0 readiness to achieve sustainable excellence. Managers should balance exploration (e.g., innovation) and exploitation (e.g., efficiency) while adopting technologies like robotics, blockchain, and smart logistics. Industry 4.0 readiness enhances ambidextrous practices' impact on sustainability and serves as both a mediator and moderator. Organizations should invest in digital infrastructure—upgrading IT systems, improving internet reliability, and adopting smart tools—to boost efficiency and meet sustainability goals.

Moreover, for policymakers and industry leaders in Egypt, this research offers insights into leveraging digital transformation to tackle challenges in the food and beverage sector. By improving Industry 4.0 readiness, organizations can navigate fluctuating supply chains, meet stringent regulatory requirements, and drive sustainable manufacturing practices. Government initiatives, such as incentives for adopting green technologies and training programs on Industry 4.0 capabilities, can further accelerate this transformation. The study provides a framework for firms to boost competitiveness and sustainability by integrating ambidextrous capabilities with Industry 4.0 technologies, such as circular economy principles and real-time data analytics, to achieve environmental, social, and economic goals. The study highlights how Egypt's food and beverage sector can use Industry 4.0 technologies to improve traceability, reduce waste, and optimize production. By fostering innovation, firms can enhance employee ambidexterity and accelerate digital tool adoption, driving sustainability, competitiveness, and manufacturing excellence.

6.2.1. Managerial insights

- Adopt Digital Technologies Strategically: Managers must focus on deploying advanced technologies such as IoT, AI, and blockchain to drive operational efficiency and support sustainability initiatives. These tools enable enhanced traceability, waste reduction, and optimization of supply chains.
- Develop a Dual-Focused Strategy: Organizations should align ambidextrous strategies (exploration and exploitation) with sustainability objectives, ensuring that operational and innovation goals are balanced to drive environmental, social, operational,

and innovation performance simultaneously.

- Enhance Workforce Capabilities: Managers should provide continuous training to employees, focusing on digital tools and Industry 4.0 technologies, to foster ambidexterity at the individual and organizational levels. This ensures readiness for adopting technological advancements.
- Leverage Sustainability for Competitive Advantage: By prioritizing sustainability across environmental, social, operational, and innovation dimensions, firms can enhance their market reputation and attract eco-conscious consumers.
- Collaborate with Policymakers: Firms should engage with government bodies to take advantage of incentives for adopting green technologies, such as tax benefits or grants, and participate in training programs to improve digital and ambidextrous capacities.
- Monitor Industry 4.0 Readiness: Regularly assessing organizational readiness for Industry 4.0 is crucial for identifying and addressing gaps in technology adoption, leadership, and operational processes to achieve sustainable excellence.

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The study provides a framework for firms to boost competitiveness and sustainability by integrating ambidextrous capabilities with Industry 4.0 technologies, such as circular economy principles and real-time data analytics, to achieve environmental, social, and economic goals. It highlights how Egypt's food and beverage sector can use Industry 4.0 technologies to improve traceability, reduce waste, and optimize production. By fostering innovation, firms can enhance employee ambidexterity and accelerate digital tool adoption, driving sustainability, competitiveness, and manufacturing excellence.

6.3. Sensitivity analysis insights

The sensitivity analysis conducted in this study quantified the relative impact of manufacturing ambidexterity and Industry 4.0 readiness on sustainable excellence. Key insights include：

- Explained Variance: The combined influence of ambidexterity and Industry 4.0 readiness explains 43% of the variance in sustainable excellence, emphasizing the substantial contribution of these variables.
- Impact Variation: Sensitivity analysis demonstrated that higher Industry 4.0 readiness levels significantly enhance the effects of ambidextrous practices, particularly in areas like environmental and innovation performance.
- Performance Dimensions: Among the four sustainability dimensions, operational and innovation performance showed the highest responsiveness to improvements in Industry 4.0 readiness, highlighting the transformative potential of digital technologies.

6.4. Limitations

While this study provides valuable insights into the relationship between manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence, several limitations should be acknowledged to contextualize the findings and guide future research. First, the study is limited to Egypt's food and beverage sector, which may restrict the generalizability of the results to other industries or regions. The unique characteristics of this sector, such as the high perishability of products and complex supply chains, may not be directly applicable to industries with different operational dynamics or sustainability challenges. Second, the research employs a cross-sectional design, capturing data at a single point in time. This approach limits the ability to analyze how the relationships among manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence evolve. A longitudinal design could provide deeper insights into causality and the long-term impacts of digital transformation and ambidextrous strategies.

Third, while the study treats Industry 4.0 readiness as a single construct, it does not explore its specific sub-dimensions, such as technological infrastructure, human capital, or organizational culture. These sub-dimensions may have

distinct effects on the adoption and impact of ambidextrous strategies, and future studies could examine these factors in more detail. Fourth, the study relies on self-reported survey data, which may introduce common method bias or social desirability bias. Although precautions were taken to ensure data quality, such as anonymity and pre-testing the survey, the subjective nature of responses may still affect the findings. Incorporating objective performance measures or triangulating data with qualitative methods, such as interviews, could enhance validity. Lastly, the study focuses on structural relationships and does not explicitly consider external factors such as government policies, market conditions, or competitive pressures. These contextual variables may play a significant role in shaping the effectiveness of ambidextrous strategies and Industry 4.0 adoption, particularly in emerging markets.

6.5. Future research directions

This study has provided valuable insights into the interplay between manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence. However, several avenues for future research could deepen understanding and broaden the application of these findings. Expanding the scope to different sectors beyond Egypt's food and beverage industry is one such avenue. Industries like textiles, automotive, and pharmaceuticals, which face unique challenges and opportunities, could benefit from applying this framework. A comparative analysis across industries would help identify sector-specific dynamics and enhance the generalizability of findings. Geographically, this study focuses on Egypt as a representative emerging market, yet the challenges and opportunities vary significantly across regions. Future research could examine other developing economies in Africa, Southeast Asia, or South America, highlighting both similarities and differences in the factors influencing ambidexterity and Industry 4.0 readiness. Comparative studies between developing and developed economies could also provide valuable insights into the influence of varying technological maturity and resource availability.

Another critical area for exploration is the detailed examination of Industry 4.0 readiness. In this study, it is treated as a single construct, but future research could dissect its sub-dimensions, such as technological infrastructure, leadership commitment, and employee capabilities, to determine their individual and combined impacts. This granular approach could offer practical recommendations for organizations aiming to enhance their readiness for adopting advanced technologies. Methodologically, this research adopts a cross-sectional design, capturing relationships at a single point in time. Future studies could adopt a longitudinal approach to explore how the relationships between manufacturing ambidexterity, Industry 4.0 readiness, and sustainable excellence evolve. Such an approach would be particularly valuable in tracking the long-term impacts of technological adoption and policy change.

Moreover, the role of government policies and incentives in fostering Industry 4.0 readiness and ambidexterity deserves further investigation. Research could examine the effectiveness of public-private partnerships and the role of subsidies or tax incentives in encouraging the adoption of sustainable practices and advanced technologies. This would provide actionable insights for policymakers in emerging economies.

Lastly, exploring the integration of specific Industry 4.0 technologies, such as blockchain, augmented reality, and additive manufacturing, with ambidextrous strategies offers another promising direction. These technologies are reshaping supply chains, improving traceability, and fostering innovation, yet their unique contributions to sustainable excellence remain underexplored. By focusing on these and other areas, future research can advance the theoretical and practical understanding of how organizations achieve sustainability in dynamic, resource-constrained environments.

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