The Influence of Digital Transformation on Enhancing Competitiveness in Agribusiness: Investigating the Mediating Role of Technology Research and Development in Agricultural Enterprises

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Abstract

This study aims to investigate how digital transformation influences the competitiveness of agricultural enterprises, focusing on the mediating role of technology research and development. The data of 367 employees in the agricultural sector were collected by convenience sampling method and analyzed by structural equation model. The findings indicate that the structural equation model of the impact of digital transformation on business competitiveness fits well with the data (CMIN/DF=1.323, CFI=0.836, AGFI=0.822, TLI=0.956, RMSEA=0.030) Digital Transformation has a significant positive impact on Business Competitiveness (β =0.277, $p<0.05$) The mediating effect value of technology research and development on digital transformation is 0.184. This research underscores the importance of advancing digital transformation to enhance the competitive edge of agricultural businesses. Agricultural enterprises in the early planting process, increase the application of digital technology in the greenhouse temperature and soil real-time monitoring. The use of digital technology research and development to improve the process management of agricultural enterprises more effectively, improve the quality of agricultural products, and create the competitive advantage of enterprises. Furthermore, the limitation of this study is that it only studies agricultural enterprises in Guangxi, China, which can be expanded the research area and other industries in the future.

Keyword: Digital Transformation, Business Competitiveness, Technology Research and Development

Introduction

Digital transformation is recognized as a pivotal trend reshaping the global economy. In 2017, the UK government demonstrated its commitment to this shift through the UK Digital Strategy, outlining comprehensive measures to advance digital transformation. Simultaneously, the German Federal Government launched the Digital Strategy 2025 in March 2016, with a strong emphasis on leveraging 'Industry 4.0' to catalyze the digital overhaul of traditional industries. On September 20, 2018, France further supported this trend by unveiling the 'Plan for Promoting Industrial Transformation through Digital Technologies,' aimed at strengthening France's local industrial ecosystem and fostering an innovative industrial centre.

Most research on the digital transformation of companies focuses on manufacturing companies (Tang et al., 2020) with few studies examining agricultural companies. This paper aims to fill this gap by studying the digital transformation of agricultural companies.

This study aims to address the existing research gap by investigating the impact of digital transformation on the competitiveness of agricultural enterprises in China, a country noted for its significant agricultural output and innovation adoption. The research focuses on how digital transformation, through systematic changes in management and production processes, can enhance competitiveness in this sector. In addition, the mediating role of technology research and development is less studied in the literature, and the mediating role of technology research and development factors provides new insights into how digital advances affect agricultural competitive advantage.

As the digital economy expands, an increasing number of nations were embracing digital transformation strategies. Recent data suggested that the implementation of enterprise digital transformation (DT) was progressing steadily and expanding across various countries (Du et al., 2022) With technological innovation accelerating, many countries now view the digital economy as a crucial driver of economic growth. (Li et al., 2016) According to the International Data Corporation, the digital economy was expected to comprise 62% of the global GDP by 2023, heralding a new era dominated by digital economic activities.

Digital transformation significantly enhances enterprise competitiveness. By integrating digital technologies, companies can revamp traditional management and production processes, thus improving operational efficiency and competitiveness

(Yao et al., 2022). In agribusiness, digital transformation not only entails upgrading technological infrastructures but also involves refining technology research and development, and enhancing business competitiveness. This complex change process requires not just the digitization of operational capabilities but also the enhancement of digital technology innovation capacity, strategic management, business competitiveness, research and development funding, technology transfer systems, and other interconnected areas. (Accenture China Company Digitalization Transformation Index Report, 2018)

Digital transformation of agricultural companies can enhance their competitiveness. In the process of studying digitalization of agriculture-related enterprises, the issue of enterprise digital transformation is not directly locked, but gradually extended from the digital development of enterprises in other fields, the operation of information tools for agriculture-related enterprises, and the development of information technology. (Cecilio et al., 2022) Digital transformation of 5agriculture-related enterprises can improve the competitiveness of enterprises The relationship between the data can be found from the digital technology, enterprise digital production and management, enterprise scale and other company data in the financial statements of listed companies. The benchmark regression results confirm that digital transformation has a significant positive promoting effect on the competitiveness of agriculture-related enterprises. (Tang et al., 2020)

Technology research and development (R&D) aims to improve processing technology, creating products with distinct performance, grade, and quality differences to avoid product homogenization competition and achieve core enterprise competitiveness. (Zhang, 2021) Scholars have already produced significant research in this area, demonstrating that R&D investment can enhance long-term innovation competitiveness, improve employee proficiency, reduce production costs, and increase corporate profits. (Tang et al., 2020) R&D innovation is on track to achieve 79% of the Sustainable Development Goals, with digital technologies enabling the production of high-quality services and products in sectors such as agriculture, thus contributing to economic development and competitiveness. (Mostafa et al., 2023)

The anticipated findings were expected to provide valuable implications for enterprise managers by highlighting the strategic importance of digital transformation and its potential to

significantly improve business operations and competitive edge. This study seeked to contribute to the empirical literature on digital transformation in agribusiness and serve as a decision-making tool for stakeholders contemplating similar transformations to enhance their competitiveness.

Objectives

Building upon the established research context, this study aims to examine the interrelationships between digital transformation and competitiveness within agricultural companies. The specific objectives are:

1. To assess the impact of digital transformation on the competitiveness of listed agricultural companies in China.

2. To explore the impact of digital transformation on technology research and development within these companies.

3. To examine the mediating role of technology research and development in the relationship between digital transformation and business competitiveness.

Literature Review

Total Factor Productivity theory is integral to this research as it provides a framework for understanding how digital transformation enhances the productivity and competitiveness of agricultural listed companies in China. (Lin et al., 2022) Digital transformation introduces advanced technologies such as big data analytics, the Internet of Things (IoT), and automation, which optimize agricultural production processes. By adopting these technologies, agricultural companies can streamline operations, reduce waste, and improve yields, thereby increasing total factor productivity. Additionally, digital transformation requires upskilling the workforce to handle new technologies effectively, enhancing human capital and overall productivity. This aligns with the research's objective to explore the impact of digital transformation on technological research and development within agricultural companies.

The first empirical finding is that firm Digital transformation can aid in increasing productivity. Quantitatively, every one-unit increase in firm Digital transformation increases productivity by 0.0066 units, measured using the TFP metric and the autocorrelation function technique. (Boger et al., 2022) Furthermore, the results of the heterogeneity analysis show that this promotion effect is strong in firms belonging to downstream industries. Our subsequent analyses suggest that firm Digital transformation boosts productivity

by improving technological innovation, human capital, operating capability, and investment efficiency, elucidating the link between firm Digital transformation and productivity gains. Further analysis elucidates the economic impact of firm Digital transformation on productivity, indicating increased profitability.

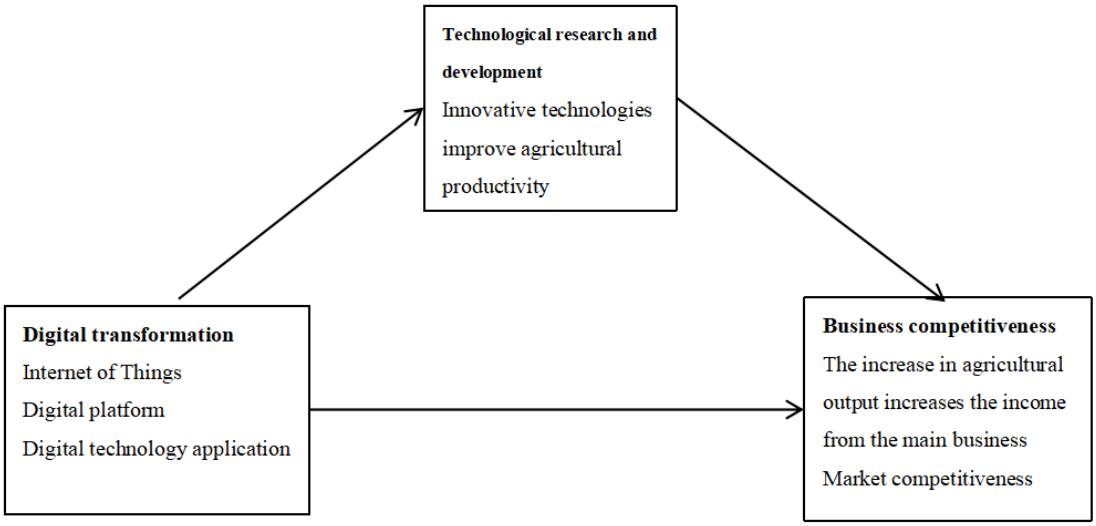

Figure 1 Technology research and development intermediary role

1. The Relationship Between Digital Transformation and Business Competitiveness

The origins of digital transformation (DT) can be traced back to the 1980s and early 1990s when researchers began exploring the impact of adopting information technology (IT) on organizational structure, hierarchy, innovation, and performance. (Boger et al., 2022) With the widespread adoption of computer technology and the growth of the Internet, IT-driven business transformation gained prominence in the 1990s, a trend that has recently been revitalized by global crises such as COVID-19. As IT systems have become more sophisticated and their capabilities have expanded, the study of DT has evolved into a robust interdisciplinary field. This field now spans several disciplines including IT, entrepreneurship, strategic management, operations management, marketing, and organizational science. (Cenamor et al., 2019)

Researchers were highly concerned with the effects of digital transformation (DT) on firm competition (Cenamor et al., 2019; Quinton et al., 2018). Generally, the proliferation of digital technologies enhances information symmetry and market transparency, thereby strengthening

the competitive advantage of incumbents. (Henry et al., 2009) Moreover, the literature indicates a correlation between firm digital transformation and firm-level characteristics that influence productivity, such as technological innovation (Ni et al., 2021), human capital (Cecilio et al., 2022), operational efficiency, and financial performance. (Peng et al., 2022) Consequently, we have identified potential mechanisms and have conducted an explicit examination to determine their impact on the productivity-enhancing effects of enterprise DT.

Based on the above discussion, digital transformation is instrumental in enhancing an organization's competitive advantage. This enhancement notably includes the impact of digital transformation on competitive advantage and the mediating role of entrepreneurs. The capacity for technological research and development is recognized as both a competitive advantage and an intermediary factor between digital transformation and business competitiveness. Digital transformation influences not only competitive advantage but also the relationship between technological research and development and business competitiveness. Managers in innovation, production, and operations, as well as service company owners, can utilize the results of this study as a basis for developing policies to enhance competitive advantage. (Shehadeh et al., 2023) Based on the discussion, the following hypothesis is proposed:

H1: Digital transformation has a significant and positive effect on business competitiveness.

2. The Relationship Between Digital Transformation and Technology Research and Development

The core feature of digital transformation was its substantial impact on the digital technology employed within an organization, as well as on the organization's digital culture and environment. (Singh et al., 2019) This transformation profoundly influences the organizational structure of technology research and development, necessitating comprehensive changes throughout the entire system. (Chanias et al., 2019) For instance, essential aspects of an organization's core strategy development may include the integration of digital transformation processes and the enhancement of technology research and development capabilities.

Kelly et al. (2021) identify technology research and development as a pivotal area within organizations, playing a crucial role in supporting the firm's digital technology advancements and facilitating

digital transformation. Digital transformation, in turn, significantly propels the development of digital technologies within the company. Lawrence et al. (1967) discuss organizational subsystems—such as sales, technology development, and production operations—that carry out specialized tasks to enhance company performance. These subsystems, termed "organizational edges," operate under varying institutional logics, interact with one another, and significantly influence competitive dynamics within firms. (Giua et al., 2022) It was evident that digital transformation substantially boosts the capabilities for research and development in technology. Based on this understanding, the following hypothesis is proposed for this study:

H2: Digital transformation has a significant and positive effect on technology research and development in companies.

3. The Relationship Between Technological Research and Development and Business Competitiveness

The processes of globalization, internationalization, and integration, coupled with the ongoing environmental impacts of the new economy, have significantly altered the paradigm of contemporary business activities. Economic realities compel enterprises to rethink their strategies and seek new competitive market strategies. (Hitchens et al., 2023) Changes in the global economy, along with the resulting uncertainty and increased risks associated with economic activities, necessitate that companies implement systemic changes and modernize their existing structures. (Podobnik et al., 2008) The implementation of modern digital technologies and innovative solutions was essential. Enhancing business competitiveness through technological research and development had become a critical requirement for economic development and corporate management transformation in the 21st century. (Boger et al., 2022) This was manifested in the openness, flexibility, and adaptability of these entities, which set them apart from the rigid structures of traditional strategic management. Moreover, it was reflected in the company's digital innovation strategy and its ability to capitalize on various digital innovation opportunities. (Boger et al., 2022)

Building on the discussion of the evolving digital economy and its transformative effects on the economic landscape, companies were actively leveraging technological innovation and the adoption of advanced digital technologies to enhance market competitiveness. This strategic integration

encompasses the continuous implementation of research and development initiatives aimed at fostering innovation. (Mostafa et al., 2023) Critical digital technologies, including next-generation networks like 4G and 5G, cloud computing, and the Internet of Things (IoT), were being extensively integrated into agricultural operations. These technologies are primarily targeted at enhancing operational efficiency, effectiveness, and sustainability. (Misra et al., 2020) Notably, the Internet of Things offered significant utility in the agricultural sector by providing farmers with sophisticated tools that facilitate remote management and real-time data access, thus addressing several operational challenges. These technological advances had markedly improved the efficiency and competitiveness of agricultural enterprises. (Fukuyama, 2018) Based on this comprehensive discussion, the study posits the following hypothesis:

H3: Technology research and development within companies exerts a significant and positive effect on business competitiveness.

4. The Relationship Between Digital Transformation, Technology Research and Development, and Business Competitiveness

Digital transformation significantly impacts business competitiveness by enhancing technology research and development. In the European high-tech industry, digital transformation reconfigures traditional business models, establishing itself as a fundamental element for industrial enterprises to maintain market competitiveness and sustainability. (Rambe et al., 2022). Llopis-Albert et al. (2021) advocated the use of fuzzy set qualitative comparative analysis to examine the future effects of digital transformation on enterprise performance models and stakeholder satisfaction. Their findings underscore the necessity for strategic investments in digital transformation, suggesting that such initiatives lead to increased profits, productivity, and competitiveness. (Llopis-Albert et al., 2021)

furthermore, Mostafa and Charla (2023) suggest that digital transformation involves the comprehensive integration of digital technologies into businesses, fundamentally altering the business environment, communication, and competitiveness. Jafar-Sadeghi et al. (2021) explore how digital transformation influences business value creation by focusing on technology entrepreneurship and market expansion. They highlight that small and medium-sized enterprises (SMEs), which are crucial to a country's

economy, benefit from digital transformation, contributing to sustainable economic development and wealth creation. Technological innovation, as they argue, was positively correlated with increased competitiveness. (Zorrilla et al., 2014)

A synthesis of the literature indicates a clear relationship between digital transformation, technology research and development, and business competitiveness. Based on these findings, the following hypothesis is proposed:

H4: Digital transformation enhances business competitiveness through technological research and development.

From the literature review, the conceptual framework is illustrated in Figure 2.

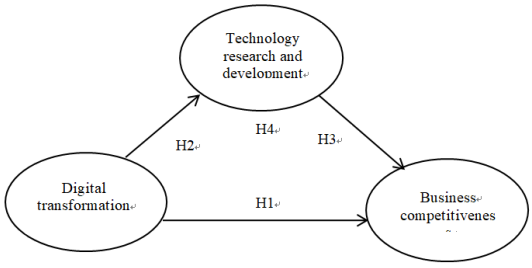

Figure 2 Conceptual Framework

Research Methodology

The research method of this study adopts quantitative method. Quantitative research is to collect numerical data, through the use of statistics and mathematical analysis to improve the degree of standardization and precision of social research. The personnel and managers of the main units of agricultural enterprises are analyzed. The research methodology employs a series of carefully selected methods to carry out this investigation effectively.

Structural equation model (SEM) is a computationally intensive method to analyze data. The SEM data analysis method can determine whether there is a direct or indirect impact between the variables of digital transformation, technological research and development, and business competitiveness. This is in line with our objectives to study the relationship between digital transformation of agricultural enterprises and business competitiveness, and the indirect impact of technological research and development.

This study utilized a sample of 367 employees from agricultural enterprises in Guangxi, calculated using the Taro Yamane formula for determining sample sizes at a 95% confidence level. Employment records from the Guangxi Agricultural Bureau indicate that the agricultural sector in this region employs approximately 4,500 individuals.

This study used the method of convenience sampling method to sample. The main objects of the pre-study were the 367 managers and employees of agricultural companies. This study required

both respondents and respondents to be enterprise employees, and familiar employees were familiar with the company's digital transformation.

Stage 1: Selection of Primary Sampling Units

The first stage involves the selection of primary sampling units, and the classification of agricultural industries by the China Securities Regulatory Commission includes: agriculture, forestry, animal husbandry, fishery, and agriculture-related manufacturing services. The main sampling unit selected Guangxi listed agricultural enterprises.

Stage 2: Allocation of Sample Size

Within each Guangxi listed agribusiness, there are at least 20 participants included in the study. This distribution ensures a balanced representation of companies.

Stage 3: Sampling Method within Cities Within each listed agricultural, a combination of convenience sampling methods was utilized to select participants. Convenience sampling is used to facilitate the accessibility of online agricultural enterprises, while conveniently ensuring the randomness of the selected samples

1. Data Collection Procedure

Participants are agri-business online platforms recruited through online surveys distributed through various channels. Collected surveys Information on digital transformation and business competitiveness, whether digital transformation can enhance the competitiveness of agricultural enterprises.

2. Ethical Considerations

This study informed the respondents in the questionnaire, which clearly stated that it did not involve commercial purposes, nor was it used for any assessment of employees by the enterprise. For academic exchanges and summaries only, we promise to keep all information provided confidential.

The data collection tool was a structured questionnaire divided into six sections. The first section collected demographic information, including gender, age, education level, job title, and educational background. Subsequent sections (2 through 6) employed a Likert scale ranging from 1 ('strongly disagree') to 5 ('strongly agree') to gauge participants' perceptions of three key constructs: digital transformation (DT), technology research and development (TRD), and business competitiveness (BC). Each construct was assessed using three observed variables.

3. Digital transformation Evaluation Scale

Digital transformation was under the extensive guidance of digital management ideas, digital transformation

makes full use of high-tech information technologies such as Internet of Things, Digital platforms and Digital technologies application, and takes transaction objects such as customers and consumers as the management focus, so that digital was widely involved in the production and operation activities of enterprises. (Cecilio et al., 2022) Digital transformation can be defined as strategic transformations targeting organizational changes implemented through digitalization projects, with the goal of enabling major business improvements. The strategic adoption of digital technologies by agricultural companied to innovate business models and processes, enhancing competitiveness within China's dynamic digital and agricultural landscape. (Cecilio et al., 2022).

4. Technology research and development Evaluation Scale

Technology Research and Development in agriculture encompasses strategic investments in innovation, technology transfer, and enhancing technological capabilities to improve product differentiation and secure competitive advantage in the sector.

Technology research and development scholars have already had some research results. Through research, it was found that the investment of research and development expenses can help improve the innovation competitiveness of enterprises in the long run, thereby improving the proficiency of employees, reducing production costs, and thus increasing corporate profits. (Tang et al., 2022)

5. Business Competitiveness Evaluation Scale Business competitiveness involves the strategic use of main business income, net profit, and market competitiveness to enhance overall business performance. This fundamental relationship is detailed in the following table, which outlines the definition and measurement of business competitiveness.

Data analysis was conducted using descriptive statistical techniques to compute frequencies, percentages, and mean values. To assess model fit, advanced statistical methods such as structural equation modeling and confirmatory factor analysis were utilized.

Results

1. Data preparation prior to SEM

Before hypothesis testing, the questionnaire data was processed to address missing values and outliers, and validity testing. Missing values refer to the absence of data for one or more attributes in an existing dataset. This study used the online questionnaire star software, collected via the WeChat mini program. If a

question is not filled out, the entire dialog does not close, and the questionnaire cannot be submitted. Therefore, there are no missing values in this study.

2. Respondent bias

Respondent bias refers to the bias in research caused by the subjective factors of the respondents. To control for this, measures such as separation of time and space were implemented during the study design and measurement process. The questionnaire was an anonymous survey, reducing the likelihood of inaccurate responses and guesswork from a psychological perspective.

Using analysis software, 367 questionnaires were tested, revealing 15 factors with eigenvalues greater than 1. The variance of the largest factor was 29.73%, less than 50%, as shown in the figure. Therefore, we can conclude that there are no significant common method biases in this study.

Table 4 Harman's Single factor test value

Ingredient	Initial eigenvalue			Extract the sum of squared loads		
	Total	Variance percentage	Accumulation %	Total	Variance percentage	Accumulation %
1	22.298	29.731	29.731	22.298	29.731	29.731
2	5.404	7.205	36.936	5.404	7.205	36.936
3	3.812	5.083	42.019	3.812	5.083	42.019
4	3.290	4.386	46.405	3.290	4.386	46.405
5	3.120	4.160	50.565	3.120	4.160	50.565
6	1.996	2.661	53.226	1.996	2.661	53.226
7	1.833	2.443	55.670	1.833	2.443	55.670
8	1.632	2.176	57.846	1.632	2.176	57.846
9	1.496	1.994	59.840	1.496	1.994	59.840
10	1.440	1.921	61.761	1.440	1.921	61.761
11	1.389	1.852	63.612	1.389	1.852	63.612
12	1.306	1.742	65.354	1.306	1.742	65.354
13	1.270	1.694	67.048	1.270	1.694	67.048
14	1.169	1.559	68.607	1.169	1.559	68.607
15	1.136	1.514	70.121	1.136	1.514	70.121

3. Univariate normal distribution

This study focuses on variables such as digital transformation, business competitiveness, technology research and development. The primary objective is to test the normality of these variables using the Kolmogorov-Smirnov test. The results indicate a "rejection of the null hypothesis," suggesting that digital transformation, technology research and development and business competitiveness do not conform to a normal distribution.

Reason Analysis: The questionnaire employed a 5-point Likert scale to evaluate digital transformation and business competitiveness. This scoring method may lead respondents to prefer higher scores. According to Bentler et al. (1987), the minimum sample size for SEM should be at least five times the number of estimated parameters (under normal distribution, without missing or perceived values) or fifteen times the sample size. In this study, 15 parameters were estimated with a sample size of 367, which exceeds the minimum requirement of fifteen times the estimated parameters. Therefore, although the sample does not meet normality criteria, it can still be analyzed using SEM.

4. Respondents' Profiles and Studied Variables

The demographic profile of the respondents revealed a majority of male participants, with 217 males (59.1%) compared to 150 females (40.9%). The age distribution showed that the largest group was between 31-35 years old, comprising 112 individuals (30.5%), followed by those aged 36-40 years, with 102 individuals (27.8%), and 41-45 years, with 80 individuals (21.8%). The smallest groups were those under 25 years old, with 16 individuals (4.4%), and those aged 51 and above, with 9 individuals (2.4%).

Regarding educational level, the most common level was undergraduate degrees, held by 159 employees (43.3%). This was followed by 142 employees (38.7%) who had completed education up to a bachelor's degree or lower. A smaller segment comprised employees with master's degrees (57, 15.5%), and a minority held PhDs (9, 2.5%).

In terms of job positions within their companies, the respondents included 248 grass-roots employees (67.6%), 67 middle-level managers (18.3%), 28 CEOs (7.6%), and 3 directors (0.8%).

5. Confirmatory factor analysis

This research focuses on three scales: the digital transformation scale, the technology research and development scale, the business competitiveness scale. To test the applicability of these three scales in the context of digital transformation in Guangxi, China,

confirmatory factor analysis (CFA) was conducted to verify the rationality of the scale model.

In the indicators obtained by CFA, the closer the subjective index X2/DF is to 0, the better the fit between the observed values and the model. An X2/DF < 3 indicates a good overall fit and suggests that the model is appropriate. An X2/DF < 5 indicates that the model is acceptable. The ranges of GFI, NFI, TLI, and CFI are between 0 and 1, with values closer to 1 indicating a better fit and a better model. Values greater than 0.9 are considered indicative of a good model fit. An RMSEA < 0.5 suggests that the measured data is in good agreement with the model.

6. Digital transformation

This study evaluates digital transformation across three dimensions, utilizing a total of 15 measurement questions. The results derived from confirmatory factor analysis were detailed in the subsequent figures and tables presented below.

The measurement of digital transformation in this study is based on tools developed by foreign scholars. The sub-dimensions of digital transformation include three main dimensions: Internet of Things (IOT), Digital Platforms (DP), and Digital Technologies Application (DTA). The samples were verified using analysis software. The standardized model diagram, shown in the figure, indicates that the value of the standardized regression coefficient (factor load) is greater than 0.5. The three factors all have values greater than 0.5, and the Composite Reliability (CR) values are all greater than 0.7, indicating that the analyzed data have good convergence validity

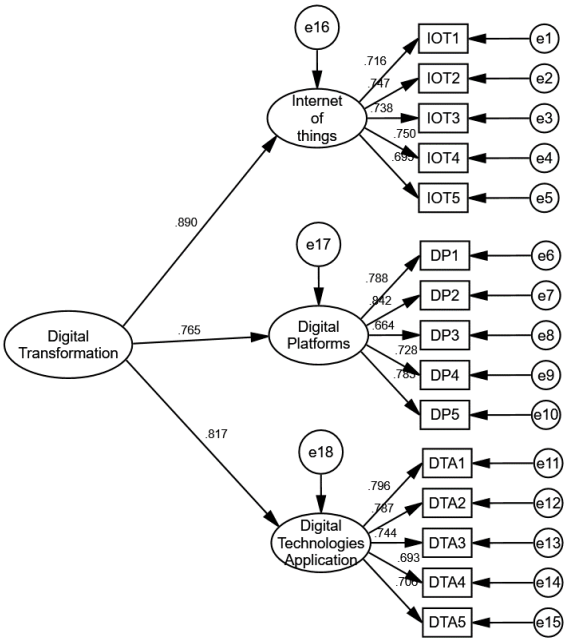

Figure 3 Digital transformation Confirmatory factor model

Table 5 Model Ave and CR index results

Variable	Item	Factor loading	CR	AVE
Digital Transformation	Internet of things	0.890	0.865	0.682
	Digital Platforms	0.765		
	Digital Technologies Application	0.817		
Internet of things	IOT1	0.716	0.850	0.532
	IOT2	0.747		
	IOT3	0.738		
	IOT4	0.750		
	IOT5	0.695		
Digital Platforms	DP1	0.788	0.874	0.583
	DP2	0.842		
	DP3	0.664		
	DP4	0.728		
	DP5	0.783		
Digital Technologies Application	DTA1	0.796	0.862	0.557
	DTA2	0.787		
	DTA3	0.744		
	DTA4	0.693		
	DTA5	0.706		

Table 6 Fit degree of confirmatory factor model

Model fit	Recommended values	Measurement model	Result
CMIN	——	195.609	——
DF	——	87	——
CMIN/DF	<3	2.248	Fit
RMR	<0.08	0.037	Fit
GFI	>0.9	0.936	Fit
AGFI	>0.9	0.911	Fit
IFI	>0.9	0.961	Fit
TLI	>0.9	0.953	Fit
CFI	>0.9	0.961	Fit
RMSEA	<0.08	0.058	Fit

The results from the table indicate that the model fits the data well. The ratio of Chi-square to degrees of freedom (CMIN/DF) was 2.248, which was below the commonly accepted threshold of 3. The Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Tucker-Lewis Index (TLI), Incremental Fit Index (IFI), and Comparative Fit Index (CFI) all exceed the critical value of 0.9. The Root Mean Square Residual (RMR) was 0.037, and the Root Mean Square Error of Approximation

(RMSEA) was 0.058, both of which were below the recommended maximum of 0.08. These indices collectively confirm that the model adheres to general research standards and is thus considered to have a good fit.

Technology research and development

There are 3 dimensions, including a total of 15 measurement questions. The following figure and table are obtained after the analysis of confirmatory factors.

The measurement of technological research and development in this paper is based on the measurement tools of foreign scholars. The sub-dimensions of technological research and development mainly include research and development (R&D), technology transfer (TT), and technological innovation ability (TI). Therefore, analysis software was used to verify the samples. The normalized regression coefficient (factor load) values are greater than 0.5 for all three factors, and the CR value is greater than 0.7, indicating that the analyzed data has good convergence validity

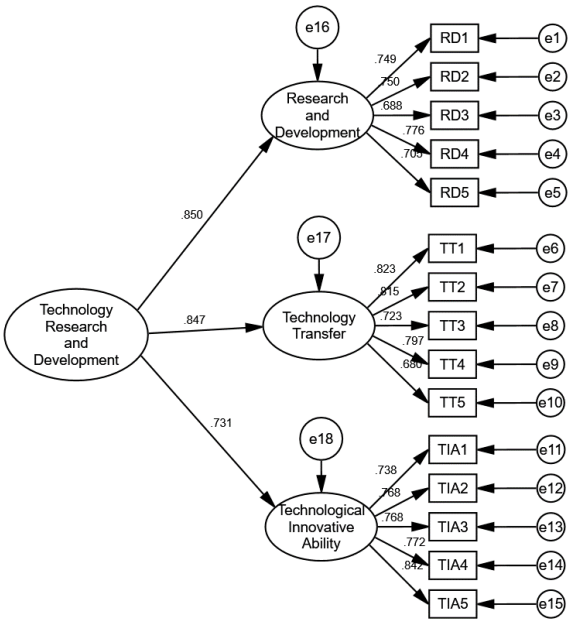

Figure 4 Finalized Model

Table 7 Model Ave and CR index results

Variable	Item	Factor loading	CR	AVE
Technology Research and Development	Research and Development	0.850	0.852	0.658
	Technology Transfer	0.847		
	Technological Innovative Ability	0.731		
Research and Development	RD1	0.749	0.854	0.539
	RD2	0.750		
	RD3	0.688		
	RD4	0.776		
	RD5	0.705		
Technology Transfer	TT1	0.823	0.878	0.592
	TT2	0.815		
	TT3	0.723		
	TT4	0.797		
	TT5	0.680		
Technological Innovative Ability	TIA1	0.738	0.885	0.606

Variable	Item	Factor loading	CR	AVE
	TIA2	0.768		
	TIA3	0.768		
	TIA4	0.772		
	TIA5	0.842		

Table 8 Fit degree of confirmatory factor model

Model fit	Recommended values	Measurement model	Result
CMIN	——	144.157	——
DF	——	87	——
CMIN/DF	<3	1.657	Fit
RMR	<0.08	0.044	Fit
GFI	>0.9	0.951	Fit
AGFI	>0.9	0.933	Fit
IFI	>0.9	0.980	Fit
TLI	>0.9	0.976	Fit
CFI	>0.9	0.980	Fit
RMSEA	<0.08	0.042	Fit

It can be seen from the above table that CMIN/DF was 1.657, which is less than the standard below 3; GFI, AGFI, TLI, IFI and CFI all reach the standard above 0.9; RMR was 0.044, less than 0.08; RMSEA was 0.042, less than 0.08; all fitting indexes are in line with the general research standards. so we can say that this model has a good fit.

7. Business Competitiveness

This study evaluates business competitiveness across three dimensions, utilizing a total of 15 measurement questions. The results of the confirmatory factor analysis were depicted in the subsequent figure and table.

The measurement of business competitiveness in this paper is based on the measurement tools of foreign scholars. The sub-dimensions of business competitiveness mainly include Main business income (MBI), Net profit (NP) and Market competitiveness (MC) Three dimensions. Therefore, analysis software was used to verify the samples. As shown in the figure, the value of the normalized regression coefficient (factor load) is greater than 0.5. All the three factors are greater than 0.5, and the CR value is greater than 0.7, indicating that the analyzed data has good convergence validity.

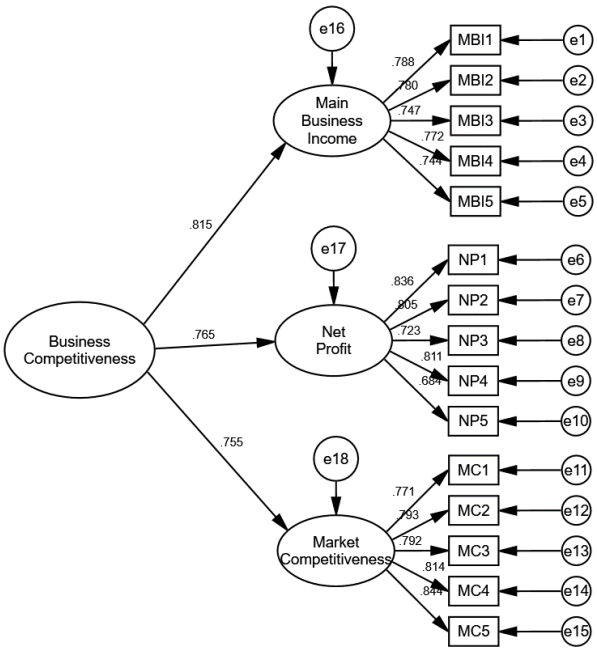

Figure 5 Business Competitiveness Finalized Model

Table 9 Model Ave and CR index results

Variable	Item	Factor loading	CR	AVE
Business Competitiveness	Main Business Income	0.815	0.822	0.606
	Net Profit	0.765		
	Market Competitiveness	0.755		
Main Business Income	MBI1	0.788	0.877	0.587
	MBI2	0.780		
	MBI3	0.747		
	MBI4	0.772		
	MBI5	0.744		
Net Profit	NP1	0.836	0.881	0.599
	NP2	0.805		
	NP3	0.723		
	NP4	0.811		
	NP5	0.684		
Market Competitiveness	MC1	0.771	0.901	0.645
	MC2	0.793		
	MC3	0.792		
	MC4	0.814		
	MC5	0.844		

Table 10 Fit degree of confirmatory factor model

Model fit	Recommended values	Measurement model	Result
CMIN	——	159.466	——
DF	——	87	——

Model fit	Recommended values	Measurement model	Result
CMIN/DF	<3	1.833	Fit
RMR	<0.08	0.046	Fit
GFI	>0.9	0.944	Fit
AGFI	>0.9	0.923	Fit
IFI	>0.9	0.977	Fit
TLI	>0.9	0.972	Fit
CFI	>0.9	0.977	Fit
RMSEA	<0.08	0.048	Fit

The fit indices from the analysis indicate an effective model alignment with the data: the Chi-square to degrees of freedom ratio (CMIN/DF) was 1.833, well below the maximum acceptable threshold of 3; Goodness of Fit Index (GFI), Adjusted Goodness of Fit Index (AGFI), Tucker-Lewis Index (TLI), Incremental Fit Index (IFI), and Comparative Fit Index (CFI) all exceed the critical value of 0.9; Root Mean Square Residual (RMR) was 0.046, and Root Mean Square Error of Approximation (RMSEA) was 0.048, both below the recommended maximum of 0.08. These results confirm that the model fits well within the accepted research standards.

For assessing discriminative validity, this study employed a rigorous Average Variance Extracted (AVE) method, following the criteria established by Fornell et al., (1981). The square root of AVE for each factor was found to be greater than the correlation coefficient between each pair of variables, indicating robust discriminative validity. The AVE square root for each construct exceeded the standardized correlation coefficients outside the diagonal line, affirming that the model exhibits sufficient differential validity. The correlation coefficients were displayed in the lower oblique triangle of the following table.

Table11 Differential validity

	DT	TRD	BC
DT	0.826		
TRD	.536**	0.811	
BC	.533**	.563**	0.778

Note: DT: Digital transformation, TRD: Technology Research and Development, BC: Business competitiveness, the bold value in the diagonal shows the square root of AVE

Final model and hypothesis analysis

Following an extensive evaluation using confirmatory factor analysis (CFA), the final model was established through structural equation modeling (SEM), as illustrated in Figure 4. The criteria used to assess the validity of the hypothesis analysis included Critical Ratio (CR), Composite Reliability (CR), and P-value.

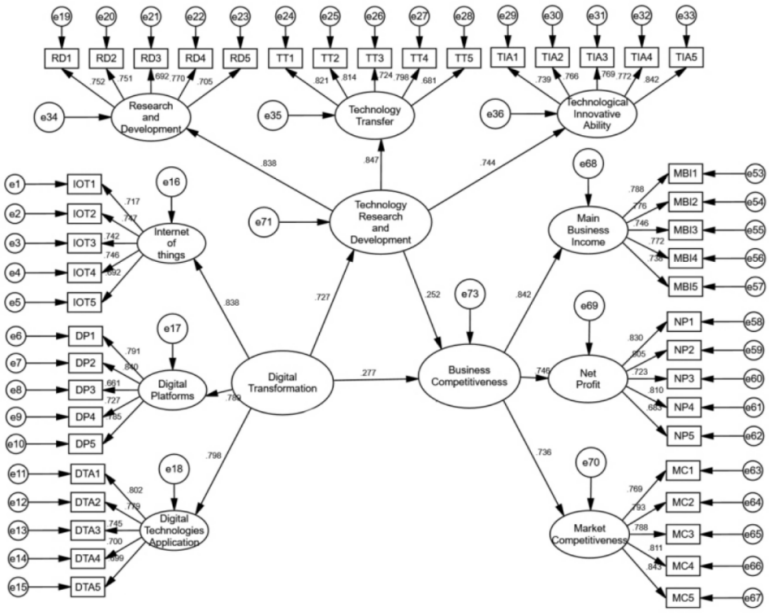

Figure 6 Final Mode

Table 12 Path Factor Values

	Estimate	S.E.	C.R.	P
Technology_Research_and Development <-- Digital_Transformation	.998	.116	8.629	***
Business_Competitiveness <-- Technology_Research_and_Development	.266	.094	2.845	**
Business_Competitiveness <-- Digital_Transformation	.400	.160	12.501	***
Lot <-- Digital_Transformation	1.000			
DP <-- Digital_Transformation	1.186	.124	9.605	***
DTA <-- Digital_Transformation	1.223	.125	9.799	***
R&D <-- Technology_Research_and_Development	1.000			
TT <-- Technology_Research_and_Development	1.115	.102	10.965	***
TIA <-- Technology_Research_and_Development	.958	.099	9.720	***
MBI <-- Business_Competitiveness	1.000			
NP <-- Business_Competitiveness	.940	.089	10.551	***
Market_Competitiveness <-- Business_Competitiveness	.919	.091	10.102	***

Note. *** P<0.001, ** P<0.01, * P<0.05

As can be seen from the above table, enterprise digital transformation has a direct prediction effect on technology research and development, and its direct prediction effect coefficient was 0.998(P< 0.001), the structural equation model shows that the predictive effect of technological research and development on business competitiveness was 0.266 (P< 0.001), the predicted effect of digital transformation on business competitiveness was 0.400 (P<0.001);

Especially when technological research and development was controlled, the impact of digital transformation on business competitiveness was significantly reduced, with an efficiency factor of 0.400 (P<0.001). Research show that technology research and development played a mediating role between digital transformation and business competitiveness.

Subsequently, the fitting indexes of the model were further developed as shown in the table. Model x^2 was 144.157, DF = 87, and the ratio of the two was 1.657. GFL, TLl and CFl were all greater than 0.9, and RMSEA = 0.042 was less than 0.08, indicating a good model fitting effect.

Table 13 Fit Index for Path Chart Analysis

Fitting indicators	x^2	DF	x^2/DF	GFI	TLI	CFI	RMSEA
	144.157	87	1.657	0.951	0.976	0.98	0.042

Form the above, assume that H1, H2, H3, H4 were accepted.

Discussion

The primary objective of this study was to explore the impact of digital transformation on the competitiveness of agricultural companies. The findings indicate that digital transformation significantly enhances business competitiveness. This positive effect is mediated by technological research and development, which plays a crucial role in amplifying the benefits of digital transformation on business competitiveness to a statistically significant extent. The results suggest that the advancement of digital transformation in agribusiness, coupled with robust technological research and development, is pivotal in enhancing business competitiveness. These findings underscore the importance of integrating advanced technologies and continuous innovation in the strategic frameworks of agricultural companies to maintain and improve their competitive edge.

The findings of this study align with previous research conducted by Yao et al. (2022) which demonstrates that digital transformation involves integrating digital technologies into business practices, fundamentally altering the business environment, communication, and competitiveness. Additionally, Jafar-Sadeghi et al. (2021) explore how digital transformation influences business value creation by focusing on technology entrepreneurship and market expansion. The concept of enterprise digital

transformation is further supported by evidence suggesting that such transformations can significantly enhance business competitiveness. As noted by Hruste (2020) by adopting digital technologies, companies can revolutionize their management and production processes, thereby improving operational efficiency and increasing competitiveness.

Technological research and development (R&D) is crucial for enhancing a company's competitiveness through promoting innovation, improving product quality, and lowering costs. By focusing on R&D investment, technology transfer, and technological innovation capabilities, companies can make significant progress and maintain a competitive advantage in their respective industries. The goal of corporate R&D investment is to improve processing techniques, create differentiated products in terms of performance, grade, and quality, avoid product homogenization, and gain core competitiveness. (Boger et al., 2022) Kelly et al. (2021) emphasize that digital transformation promotes enterprise digital technology innovation, and digital technology research and development enhances business competitiveness. Due to the intermediary role of digital transformation, enterprise digital transformation strengthens business competitiveness through the development of digital technology.

This study significantly contributes to the understanding of digital transformation within the agricultural sector. It elucidates the key factors influencing digital transformation in agriculture-related companies and clarifies the theoretical mechanisms by which digital transformation impacts this sector. By integrating and expanding upon existing theories of digital transformation, this paper enhances our comprehension of how these processes affect agricultural companies specifically. It provides a robust theoretical framework that academic researchers can utilize to further explore and develop the theories of digital transformation in agricultural contexts. Furthermore, the insights gained from this research offer valuable theoretical support for entrepreneurs in traditional agriculture looking to implement digital transformation strategies. These contributions not only advance academic discourse but also provide practical guidance for enhancing competitiveness and innovation in agricultural enterprises.

1. Recommendations at the practical action

Entrepreneurs, middle and senior managers can now enhance the competitiveness of agricultural enterprises

through the research and development of digital technology. Agricultural enterprises should increase the application of digital technology in real-time temperature and soil monitoring in greenhouses during the early planting process. Subsequently, the maturity of agricultural products can be monitored through digital technology. The research and development of digital technology can be used more effectively to improve the process management of agricultural enterprises, enhance the quality of agricultural products, and create a competitive advantage for the enterprise.

2. Limitations and Future Research

The insights in this study come primarily from the agricultural sector and may not capture the subtle impact of digital transformation across different industries. Future research should explore other industries, such as manufacturing, retail, or services, where digital transformation may behave differently. The authors cover a wide range of industries, and future research could provide a more comprehensive view of how digital advances affect competitiveness across industries. This study is limited to the agricultural sector in Guangxi and may not reflect the diverse conditions and challenges faced by agribusinesses in other regions. Future studies should aim to include multiple geographic regions with different environmental and economic conditions. The broader scope contributes to a more complete understanding of the impact of digital transformation on the competitiveness of agribusiness.

Reliance on quantitative data may not fully capture the complex strategic impact of digital transformation on business operations. To enrich the findings, future research could employ qualitative methods, such as in-depth interviews or case studies, to explore the personal experiences of managers and employees dealing with digital transformation. This approach can provide deeper insight into the specific challenges and opportunities encountered during digital transformation.

The current study provides a snapshot of the impact of digital transformation, but does not take into account the dynamics of this ongoing process. Future research should employ longitudinal studies that track the evolution of digital transformation initiatives over time and their ongoing impact on business competitiveness. This helps to understand the immediate and long-term implications of digital transformation for agri-businesses.

Future research should further explore how external factors such as policies, technological advances, and market dynamics influence the process and

effects of digital transformation. This helps to understand the complexity and dynamics of digital transformation and provides a more comprehensive guide for agri-businesses to develop effective digital strategies. While this study focused on internal factors, such as technology research and development, future research should consider external factors, such as regulatory changes, market dynamics, and competitive pressures, which may also affect the success of digital transformation. Examining the interactions between these external factors and digital transformation efforts will provide additional information for a comprehensive understanding of the drivers and barriers to achieving competitive advantage.

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