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ADDRESSING CHALLENGES IN VIETNAMESE COFFEE PRODUCTION: A TECHNOLOGICAL COOPERATIVE APPROACH

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ABSTRACT

The coffee industry in Vietnam faces significant challenges, particularly in adopting modern technologies for production. With 95% of coffee cultivated by small-scale farmers, many are struggling with low productivity, market volatility, and limited access to advanced technologies, which has led to widespread uprooting of coffee trees. This research aims to explore the key barriers faced by small-scale coffee farmers and propose a cooperative model that integrates Data and Blockchain technologies to enhance production efficiency and business practices. To achieve this, we conducted semi-structured interviews and surveys with coffee farmers, using descriptive statistics and qualitative analysis to identify critical challenges and the role of government policies in shaping the industry. The proposed solution involves the creation of a cooperative network leveraging Blockchain and Data technologies to improve the sustainability, traceability, and profitability of coffee production and distribution.

Keyword: Coffee, Cooperative, Production, Technology, Vietnam

The global coffee industry is a major sector in international trade, experiencing significant growth driven by a 65% increase in demand for coffee. This surge in demand can be attributed to coffee's dual role as both a widely consumed beverage and a key raw material for various industries, including pharmaceuticals, cosmetics, and fertilizers (Huynh and Popova, 2023a). In Vietnam, coffee cultivation plays a vital economic role, particularly in the Central Highlands region, generating substantial foreign exchange revenues through exports, which range from 2.9 to 3.9 billion USD annually (Popova *et al.*, 2023).

Research by UNIQUE Forestry & Land Use *et al.* (2018) highlights that small-scale farmers dominate coffee production globally, with approximately 6,00,000 smallholder households contributing 95% of total coffee output (UNIQUE Forestry & Land Use *et al.*, 2018). However, these farmers face numerous challenges, including limited access to investment capital, rising production costs, and volatile market prices. Consequently, many farmers are abandoning traditional coffee cultivation in favour of growing more lucrative fruit-bearing trees, a shift that undermines both their economic stability and the long-term viability of the coffee industry in Vietnam (Huynh and Popova, 2023b). Additionally, the coffee pricing system in Vietnam is heavily influenced by a network of intermediaries, including coffee roasters and trading agents. The reliance on these intermediaries often leads to economic losses and diminished control over pricing for coffee producers (Popova *et al.*, 2023). While technological advancements have the potential to improve labor productivity, enhance product quality, and streamline agricultural transactions by reducing intermediaries, many Vietnamese coffee farmers still rely on outdated and inefficient machinery due to limited financial resources and insufficient knowledge of modern technology.

As global consumers become increasingly concerned about food safety, product quality, and origin, the continued use of antiquated production methods may limit access to international markets for Vietnamese coffee producers. This study seeks to address these challenges by conducting field research in Vietnam's Central Highlands, with the goal of proposing actionable solutions that will enable coffee farmers to overcome production obstacles and align with the Vietnamese government's broader economic development objectives and the strategic direction of the coffee industry.

MATERIALS AND METHODS

The methodological significance and practical value of this study are closely tied to advancing coffee production technology, enhancing economic efficiency, and refining support programs for coffee development in alignment with the Vietnamese government's digital transformation agenda for the agricultural sector by 2030. To gather comprehensive data on production technology, costs, post-harvest income, challenges

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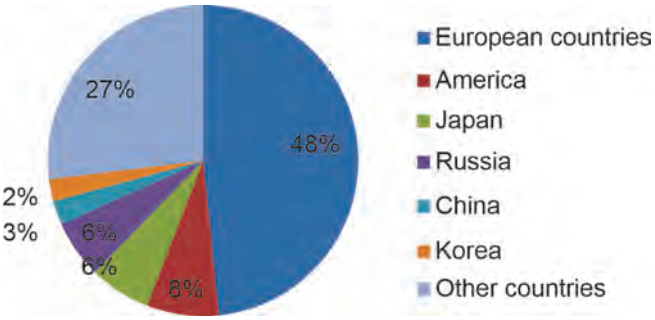
hindering development, the support farmers receive, and the activities of farmers involved in agricultural cooperatives, the study employed semi-structured interviews and surveys. Data were collected from 100 coffee-producing households across urban, rural, and village areas. The survey employed a random sampling approach, ensuring representation from both smallholder farmers and larger-scale producers with established businesses across five provinces in Vietnam's Central Highlands: Daklak, Gia Lai, Lam Dong, Kontum, and Dak Nong. The questionnaire covered several key areas: general demographic information of producers, production and harvest costs, support policies, machinery and technology usage, and product consumption patterns.

Descriptive statistics and synthetic statistical methods were applied to analyze the state of coffee production in Vietnam, the position of Vietnamese coffee in the global market, and the challenges faced by farmers. Additionally, the study examined the types of machinery and equipment used in coffee cultivation and processing. Pearson correlation analysis was employed to explore the relationship between labor productivity and the machinery utilized. The study also assessed the current status of coffee production cooperatives, the operations of coffee cooperative unions, and government policies supporting collective economies and coffee cooperatives. By using synthetic methods, the study identified key challenges that reduce the performance and efficiency of these cooperatives. To evaluate the effectiveness of cooperatives, criteria were developed for establishing coffee cooperative unions that integrate technology into production and business operations. The SMART goal-setting model (Doran, 1981) and the production function theory (Inshakova, 2021) were applied to assess labor productivity and production efficiency within cooperatives receiving technological support and government assistance. These frameworks align with the strategic directives set forth by the Central Party Resolution No. 20-NQ/TW (June 16, 2022), which focuses on promoting innovation and improving the collective economic efficiency in Vietnam's coffee industry, and the Prime Minister's Directive No. 19/CT-TTG (June 3, 2023), which emphasizes advancing digital transformation in cooperative economic zones.

Data were gathered from 100 farmer households, managers of the Department of Agriculture and Rural Development in the five Central Highlands provinces, and supplementary sources, including reports from the Vietnam Coffee and Cocoa Association (VICOFA), the Ministry of Agriculture and Rural Development, the General Department of Customs, the Statistical Report on Socio-Economic Conditions in the Central Highlands, and the Online Law Library. A random sample was selected, with interviews distributed evenly across the five provinces. Additionally, some farmers were recommended by local Departments of Agriculture and Rural Development as exemplary producers.

RESULTS AND DISCUSSION

Currently, Vietnam's coffee production spans 7,10,591 hectares, with the majority of the cultivation concentrated in the Central Highlands, which accounts for 91.2% of the country's total coffee-growing area (VICOFA, 2021, 2024). Annually, coffee exports represent 95% of the country's total coffee production (Huynh and Popova, 2023b). The largest export market for Vietnamese coffee is the European region, particularly Germany, followed by significant markets in the United States, Japan, Russia, China, South Korea, and other countries (Fig. 1).



Source: Vietnam Coffee and Cocoa Association, 2024

Fig. 1. Share of coffee exports to major markets in 2022

A survey of 100 farmers, including 32 high-productivity farmers in the Central Highlands region, reveals significant differences in production practices. Over the years, these high-productivity farmers have acquired substantial amounts of land from smaller-scale producers. They have invested in modern machinery and equipment, enabling them to engage in more extensive business activities. In contrast, 68 small-scale farmers typically do not invest heavily in machinery and equipment. However, some of these farmers do receive technical support and machinery from coffee companies, such as Trung Nguyen Coffee Group and Nestle Vietnam, to improve their production capabilities.

Currently, there are three types of irrigation systems used for coffee cultivation: drip irrigation, submersible pumps, and automatic valve watering machines with overflow water pumps. Drip irrigation and submersible pumps are modern, water-efficient systems that are also cost-effective in terms of both water and electricity consumption. Approximately 56% of farmers employ these advanced irrigation systems, while 44% still use automatic valve watering machines and overflow water pumps, which tend to waste water, electricity, and may even wash away fertilizers, depriving coffee plants of

Table 1. Survey results on equipment usage in coffee production by 100 Vietnamese farmers

Equipment and machinery used by farmers to grow and process coffee	Used by (No.)	Not used by (No.)
Drip watering machine	56	44
Lawn mower	73	27
Seed peeling machine	96	4
Coffee bean washing machine	21	79
Coffee bean sorting machine according to size	18	82
Coffee bean color sorting sensor	8	92
Coffee roasting machine	22	78
Coffee grinder	22	78
Submersible water pump	56	44
Pneumatic pesticide sprayer	22	78
Automatic valve watering machine	34	66
- Overflow water pump	10	90
- Soil analyzer	23	77

Source: Authors calculations based on survey results

essential nutrients. Regarding post-harvest processing, most farmers (96%) own coffee husking machines. The extent of investment in other machinery varies. Approximately 21% of farmers have coffee washing machines, 18% possess coffee sorting machines that classify beans by size, and 8% utilize machines that sort beans by color, primarily for business purposes. These farmers often have the financial capacity to not only invest in their own production but also to provide sorting services to other small-scale farmers. Additionally, 23% of farmers use soil analysis machines for cultivation, which are mainly provided and supported by Nestle Vietnam for farmers supplying coffee beans after harvesting (Table 1).

The survey results indicate that the adoption of technology, particularly in irrigation systems, plays a crucial role in determining both coffee yield and production costs. Water is a key factor influencing the flowering efficiency of coffee plants and directly impacts the yield. Drip irrigation systems, which represent the most advanced irrigation technology, have been shown to maintain optimal soil moisture levels, thereby improving coffee yield. These systems are automated, underground-installed, and often paired with submersible pumps, making them the most efficient and cost-effective in terms of water and electricity use. In contrast, automatic valve irrigation systems, introduced in 2003, allow for automatic rotation of irrigation direction but lack the capacity to control the water supply automatically, leading to excessive water usage and higher labor costs. Meanwhile, overflow irrigation systems, the oldest technology in use, utilize large pipe pumps to discharge water at the base of coffee trees. However, this system has significant drawbacks, including water and electricity wastage, increased labor costs, and the potential for nutrient loss due to the washing away of fertilizers. Most small-scale producers still rely on automatic valve irrigation systems and overflow pumps, primarily due to the high installation costs of drip irrigation systems. These producers, who often face financial constraints, may be unable to afford the more efficient drip irrigation technology, thereby limiting their ability to optimize water use and increase yields.

When analyzing the relationship between coffee yield and the machinery used in production, it is important to consider additional interrelated factors such as production area and access to credit. The size of the production area often determines the level of investment that farmers can make in modern technology. Larger-scale producers are more likely to invest in advanced irrigation systems, which, in turn, improve productivity. On the other hand, small-scale producers, with limited land and financial resources, are less likely to invest in such systems, which can constrain their yield potential. Access to credit also plays a critical role in enabling small-scale producers to invest in modern machinery and technology. Without access to financial support, many farmers are unable to purchase high-cost equipment like drip irrigation systems, soil analysis machines, or coffee processing equipment. As a result, they continue to rely on outdated and inefficient technologies, which reduces overall productivity and profitability.

The results of the Pearson correlation analysis reveal several key relationships between technology use, production factors, and coffee yield among the 100 surveyed coffee producers in Vietnam. A strong positive linear relationship was found between coffee yield per

Table 2. Pearson correlation for coffee production factors

		The current yield of coffee as measured in tons/ha	Number of machines used	Access to bank loans for production	Coffee cultivation area
The current yield of coffee as measured in tons/ ha	Pearson correlation	1	0.778**	0.460**	0.391**
	Significance (2-tailed)		0.000	0.000	0.000
	N	100	100	100	100
Number of machines used	Pearson correlation	0.778**	1	0.701**	0.735**
	Significance (2-tailed)	0.000		0.000	0.000
	N	100	100	100	100
Access to bank loans for production	Pearson correlation	0.460**	0.701**	1	0.633**
	Significance (2-tailed)	0.000	0.000		0.000
	N	100	100	100	100
Coffee cultivation area	Pearson correlation	0.391**	0.735**	0.633**	1
	Significance (2-tailed)	0.000	0.000	0.000	
	N	100	100	100	100

**Significant at *p=0.01* level (2-tailed)
Source: Authors calculations using SPSS statistical software

hectare and the number of machinery and equipment used in production, with a correlation coefficient of *r = 0.778* and a *p*-value of *0.01*, indicating 99% statistical significance. This suggests that producers who utilize more machinery and technology in their production processes tend to achieve higher coffee yields, and vice versa. Labor productivity also shows a positive correlation with access to credit, with *r = 0.460* and a significance level of *0.01*. However, this relationship is weak and not particularly robust, indicating that while credit access may support labor productivity to some extent, it is not the sole determining factor. Similarly, coffee yield exhibits a positive linear relationship with the production area, with *r = 0.391* and a significance level of *0.01*. Although statistically significant, this relationship is not as strong, suggesting that larger land areas alone do not guarantee higher yields without technological investment. An interesting finding from the analysis is the strong positive correlation between access to credit and the number of machinery and equipment used in production, with *r = 0.701* and a significance level of *0.01*. This indicates that those with better access to credit, such as bank loans, tend to invest more in technological machinery and equipment for their coffee production, which, in turn, likely contributes to higher yields. Moreover, there is a strong positive linear correlation between the quantity of machinery used in production and the land area cultivated, with *r = 0.735* and a significance level of *0.01*, suggesting that larger landholders are more likely to invest in additional technological equipment for their production processes. This correlation further highlights the importance of machinery in increasing productivity and coffee yield. In summary, the correlation analysis suggests that the use of advanced machinery and technology plays a critical role in enhancing coffee yield. Larger landholders are more inclined to invest in technology, which ultimately boosts productivity. For smallholder farmers, achieving high production levels may be challenging without collective efforts, such as cooperation within coffee production cooperatives. As the analysis shows, mutual cooperation may provide the necessary support for smaller producers to access credit and invest in technological advancements, improving their overall productivity (Table 2).

After analyzing the correlation between technological machinery, a strong positive correlation with labor productivity in coffee production in Vietnam was found. However, it is necessary to assess the actual impact of technology and other factors on labor productivity. Therefore, we conducted a multiple regression analysis with labor productivity as the dependent variable (Y), and the independent variables being X_1: Number of machines used, X_2: Access to bank loans for production, and X_3: Coffee cultivation area.

The equation of multiple linear regression is as follows:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon$$

where: β_0 is the regression constant (the intercept coefficient), and β_1, β_2, β_3 are the regression coefficients, while ε is the error term.

To test the fitness of the regression model, we put forward the hypothesis H_0: $R^2 = 0$. The *F*-test is used to test this hypothesis. The test result is as follows:

Significance < *0.05*: Null hypothesis H_0 is rejected, which means that $R^2 \neq 0$, indicating that the regression model fits.

Significance > *0.05*: Null hypothesis H_0 is accepted, which means that $R^2 = 0$, indicating that the regression model does not fit.

The significance value of the *F*-test is *0.000 < 0.05*; therefore, the regression model is suitable (Table 3).

The Model Summary table reveals that the R^2 value is *0.679*, and the adjusted R^2 is 0.669. This indicates that the independent variables included in the regression analysis account for 66.9% of the variation in the dependent variable, while the remaining 33.1% can be attributed to external factors and random errors. The Durbin-Watson statistic is 1.531, which falls within the acceptable range of 1.46 to 1.63 for a sample size of N = 100 and 3 independent variables. This suggests that the assumption of first-order autocorrelation is not violated, indicating that the model does not exhibit significant autocorrelation in the residuals (Table 4).

The assessment of the regression coefficient of each independent variable is determined to be significant in the model or not based on the *t*-test (Student's *t*-test) with the hypothesis H_0: The regression coefficient of the independent variable X = 0. In the regression model that has several independent variables, we tested the corresponding null hypotheses H_0. The test results are as follows:

Significance < *0.05*: The hypothesis H_0 is rejected, which means that the regression coefficient of the variable $X \neq 0$ has statistical significance, indicating that the variable X affects the dependent variable.

Significance > *0.05*: The hypothesis H_0 is accepted, which means that the regression coefficient of the variable X = 0 does not have statistical significance, indicating that the variable X does not affect the dependent variable. Coefficient of the variable X = 0 has statistical significance, the variable X does not affect the dependent variable. According to the results of the *t*-test coefficient table (Student's *t*-test), the variable "Access to bank loans for production" has a *t*-test significance value of *0.332 > 0.05*, so this variable is not significant in the regression model; this independent variable has no impact on the yield of harvested coffee. The variables "Number of machines used" and "Coffee

Table 3. ANOVA results for factors influencing coffee yield

Model		Sum of squares	*df*	Mean square	*F*	*Significance*
1	Regression	35.666	*3*	11.889	*67.760*	*0.000*[b]
	Residual	16.844	*96*	0.175		
	Total	52.510	99			

a. Dependent variable: The current yield of coffee is measured in tons/ha
b. Predictors: (constant), Coffee cultivation area, Access to bank loans for production, Number of machines used
Source: Authors calculations using SPSS statistical software

Table 4. Model Summary[b] for factors affecting coffee yield per hectare

Model	*R*	R^2	Adjusted R^2	Standard Error of estimate	Durbin-Watson
1	*0.824*[a]	*0.679*	*0.669*	0.419	1.531

a. Predictors: (constant), Coffee cultivation area, Access to bank loans for production, Number of machines used
b. Dependent variable: The current yield of coffee is measured in tons/ha
Source: Authors calculations using SPSS statistical software

Table 5. Coefficients[a] and collinearity statistics for coffee yield model

Model		Unstandardized coefficients		Standardized coefficients	*T*	Signifi-cance	Collinearity statistics	
		B	Standard error	Beta			Admission	VIF
1	(Constant)	2.352	0.134		17.586	0.000		
	Number of machines used	0.332	0.029	1.109	*11.620*	*0.000*	0.367	2.724
	Access to bank loans for production	-0.122	0.125	-0.081	*-0.974*	*0.332*	0.478	2.091
	Coffee cultivation area	-0.052	0.012	-0.372	*-4.236*	*0.000*	0.432	2.313

a. Dependent variable: The current yield of coffee is measured in tons/ha
Source: Authors calculations using SPSS statistical software

cultivation area" have *t*-test significance values of *0.000 < 0.05*, indicating that both of these variables influence the dependent variable.

To assess the hypothesis of multicollinearity, we examine the Variance Inflation Factor (VIF) values. According to Hair Jr. *et al.* (2010), a VIF value above 10 indicates strong multicollinearity, while VIF values ranging from 3 to 5 suggest potential multicollinearity if the correlation coefficient between variables exceeds 0.82. In this study, the VIF values for all independent variables are below 3, indicating that multicollinearity is not a concern. Therefore, the data do not violate the assumption of multicollinearity (Table 5).

Using the B regression coefficients, we can build a non-regularized regression model as follows:

$$Y = 2.352 + 0.332\ X_1 - 0.052\ X_3 + \varepsilon$$

When using non-regularized regression coefficients, direct comparison of results becomes difficult because the units and standard errors for each variable differ. To address this issue, it is necessary to use standardized coefficients. Standardized coefficients transform all variables onto the same scale, allowing for meaningful comparisons across variables, regardless of their original units. This ensures that each variable is assessed on an equal footing, providing clearer insights into the relative importance of each independent variable in predicting the dependent variable.

Using the Beta coefficients, we can build a standardized regression model to compare the effects of the independent variables on the dependent variable as follows:

$$Y = 1.109X_1 - 0.372\ X_3 + \varepsilon$$

The standardized regression model results indicate that the number of production machines has the most significant impact on harvested coffee yield. As the use of production machinery increases, so does the yield, highlighting the importance of technology in improving productivity. According to a survey of 100 households, the majority of small-scale coffee farmers face several challenges in coffee production. The key difficulties reported include a lack of capital for production (96%), limited access to export markets (32%), primarily affecting business-oriented farmers, seasonal labor shortages during harvesting (26%), particularly among small-scale farmers, unstable coffee prices (17%), and a lack of technology (12%) (Table 6).

Based on the results of in-depth interviews, the majority of farmers face a lack of capital for production. However, those engaged in business activities tend to have easier access to government-subsidized loans compared to small-scale producers. Most small-scale farmers lack collateral assets, which limits their ability to secure loans with preferential interest rates. Those facing technological challenges are typically larger-scale producers seeking to change their harvesting methods. These producers aim to reduce reliance on external labor and enhance their operations through the use of machinery, ensuring that coffee beans are harvested at full ripeness. The shortage of labor often leads to premature harvesting, which negatively impacts the quality of the coffee beans.

Cooperation to develop coffee production in Vietnam. To align with the state's direction and policies on digital economic development, authorities at all levels, from the central government to local administrations, have issued various directives and guidelines to enhance the economic efficiency of cooperatives in the new period. For instance, Decision No. 167/QD-TTg, dated February 3, 2021, approved by the Prime Minister, outlines a project to select, improve, and replicate effective new cooperative models nationwide from 2021 to 2025. Following this, Daklak province issued Resolution No. 19/2021/NQ-HDND on December 21, 2021, to support the development of the collective economy in the province during the 2021-2025 period. In 2022, the Party Central Committee adopted Resolution No. 20-NQ/TW on June 16, 2022, emphasizing the continued innovation, development, and improvement of the efficiency of the collective economy. Furthermore, in 2023, the Prime Minister issued Directive No. 19/CT-TTG on June 3, 2023, to promote digital transformation in cooperative economic zones and cooperatives. In line with these guiding documents on cooperative development and

Table 6. Challenges faced by coffee producers

		Respondents' response in	
		Numbers	**Percent**
What challenges do you face when producing coffee?	Scientific and technological	12	12%
	Financial	96	96%
	Difficulty entering the export market	32	32%
	Difficulty hiring workers	26	26%
	Unstable selling price	17	17%

Source: Author compilation based on the survey

digital transformation, various provinces have followed suit with specific plans to implement these initiatives. Daknong province, for example, issued Directive No. 09/CT-UBND on July 19, 2023, from the Provincial People's Committee to accelerate digital transformation in cooperative economic areas (Daknong 2023a,b). Similarly, Kontum province issued Plan No. 2950/KH-UBND on September 7, 2023, outlining the development of the collective economy and cooperatives for 2024. Lamdong province issued Plan No. 5491/KH-UBND on June 26, 2023, for the period 2023-2025, while Gialai province issued Plan No. 1116/KH-UBND on May 11, 2024, focusing on cooperative development for 2024. These provincial-level initiatives reflect the government's commitment to fostering a more dynamic and digitally-enabled cooperative economy, crucial for the sustainable development of Vietnam's coffee industry.

According to the collective and cooperative economic development plan of the Central Highlands provinces, although there is a high number of agricultural cooperatives, they suffer from a lack of quality and effective management. There are no specific statistics or separate management structures for the coffee sector within the agricultural sector at the local level. The management boards of these cooperatives are understaffed, with an average of only 3 to 4 managers per cooperative. Additionally, the cooperatives fail to establish a proper management system for their operations and do not have dedicated departments responsible for production and business activities, as required by the Cooperative Law No. 23/2012/QH13. Moreover, the management personnel within these cooperatives often lack the necessary administrative and professional qualifications. Approximately 50% of cooperative managers have not received formal training, which further limits the effectiveness and efficiency of their operations.

In Daklak, out of 499 cooperatives, 73 (14.36%) are inactive. The region has a total of 2,329 management personnel, of which 429 (18%) hold college or university degrees, 931 (40%) have vocational training, and 978 (42%) lack any formal training (Daklak, 2023). In Gialai, out of 354 cooperatives, 67 (18.93%) are inactive. There are 1,114 management personnel, with 223 (20%) holding college or university degrees, 434 (39%) having vocational training, and 457 (41%) either undergoing short-term training or lacking formal training (Gialai, 2024). In Kontum, there are 180 cooperatives, with 41 (22.78%) inactive. The province has 620 management personnel, of which 165 (26.6%) hold college or university degrees, and 455 (73.4%) have vocational training (Kontum, 2023). In Lam Dong, there are 329 agricultural cooperatives, with 47 (14.29%) inactive. The region has 1,313 management personnel, with 303 (23.08%) having vocational training, 279 (21.15%) holding college or university degrees, and 731 (55.68%) lacking formal training (Lamdong, 2023).

According to research conducted by Thi Phuong Mai Nguyen at the Vietnam Institute of Sociology, several factors contribute to the failure of new-style cooperatives, including weak professional competence and management capacity among cooperative leaders, a lack of common capital contributions, and an absence of mutual trust among members (Nguyen, 2021). Cooperatives often operate inefficiently, with their success largely dependent on business performance, financial management, and member services. Additionally, many cooperatives lack formal business ownership, are largely run on a member or family basis, or are established for local political purposes (Tran *et al.*, 2023).

Reports from the Cooperative Alliance in various regions, as well as scientific studies, consistently point to weak professional skills and management capabilities as a key reason for the failure of cooperatives. However, these studies also highlight that a lack of capital contributions and limited cultivated land area contribute significantly to the challenges faced by cooperatives. Many cooperatives, it seems, exist primarily as names on paper, with no significant changes in production and business activities compared to the period before they became cooperatives.

The results from surveys and in-depth interviews further illustrate these challenges. Of the 100 households surveyed, only 7 coffee production households were members of agricultural cooperatives. These 7 households received support from the cooperative in terms of post-harvest product marketing, bypassing intermediaries, with the cooperative purchasing coffee beans directly from the farmers. However, these households continued to operate independently, farming and producing coffee without any management or support throughout the production process, from caring for coffee trees to harvesting the fruits. There were no changes in their activities before and after joining the cooperative, and cooperative members did not have formal agreements for capital contributions, land cultivation, or machinery to support the cooperative's collective production and business activities. Additionally, no written commitments were made regarding the rights and responsibilities of participating in the cooperative (Table 7).

The government has established the Vietnam Cooperative Support Fund under Article 24 of Cooperative Law No. 17/2023/QH15, which aims to support cooperatives in their digital transformation and the application of e-commerce in production and product circulation. The fund helps build information technology

infrastructure, provides end devices and software applications for shared use, and offers funding for technology transfer advisory services to cooperatives, cooperative unions, and cooperative federations, based on needs and contracts with service providers (Vietnam National Assembly, 2023).

As part of the collective economic development plan for cooperatives in the Central Highlands provinces, the Department of Science and Technology collaborates with other organizations to provide short-term training on digital transformation. However, these courses mainly introduce the concept of digital transformation without yielding tangible results after their completion. For example, the Department of Science and Technology of Gia Lai province, in collaboration with other units, has organized short-term training for the leaders of 24 coffee-producing cooperatives on "Digital Transformation in Agricultural Supply Chain Management." The Vietnam Cooperative Support Fund has made strides in supporting specific cooperatives. For instance, it has supported 4 cooperatives with 5 loan disbursements totaling 11.1 billion VND (equivalent to approximately 462,500 USD) to invest in transportation vehicles, machinery, and equipment. This funding has also been used to support the application of advanced machinery and equipment in coffee processing, particularly benefiting agricultural cooperatives and the Nam Yang service cooperative in Gia Lai province (Gialai, 2024). However, many cooperatives in other regions have been unable to fully utilize the support from the Cooperative Support Fund for digital transformation. While the funding exists, its impact on agricultural cooperatives, particularly coffee cooperatives, remains limited, highlighting the need for more effective implementation and support systems tailored to the specific challenges of the coffee industry.

Assessing the effectiveness of cooperatives in Vietnam is done annually through self-assessments conducted by the Board of Directors, based on criteria specified in Circular No. 01/2020/TT-BKHDT issued by the Ministry of Planning and Investment in 2020. The criteria are divided into three groups:

1. **Criteria related to finances**: These include cooperative capital, cooperative assets, production and business results for the year, and the establishment of cooperative funds.
2. **Criteria on governance, management, and capacity**: This group includes compliance with laws in the organization and activities of the cooperative, resolution of disputes and complaints, the level of managerial and leadership staff, policies for members and workers, and the degree of application of scientific and technical progress, brand building, and value chain.
3. **Criteria on members, benefits to members, and the community**: This group assesses member participation rates, benefits to members, products and services provided by the cooperative, information and communication activities, training and development, positive impacts on the community, and any rewards received by the cooperative during the year.

Despite the comprehensive framework for self-assessment, many cooperatives struggle to evaluate their own effectiveness due to structural weaknesses. Many cooperatives were not formed as independent economic organizations, and they lack common assets or regulatory capital, which hinders their ability to meet the criteria for self-assessment. Additionally, many provinces have not reported on the evaluation of cooperative activities at the local level.

For instance, in Gia Lai province, out of 354 cooperatives, 227 (64.13%) cannot self-assess according to the criteria set by the Ministry of Planning and Investment. Furthermore, 42 cooperatives (11.86%) self-assessed as weak in operation, and only 24.01% of cooperatives maintained operations at an average level or higher (Gia Lai, 2024). This indicates that the quality of agricultural cooperatives' operations remains low, with many failing to adhere to the guidelines for establishing and operating cooperatives in line with the goals of digital economic development for the collective economy.

The research on collaborative production and business activities of coffee farmers and agricultural cooperatives (including coffee cooperatives) has revealed several key shortcomings that contribute to low operational efficiency. These issues include:

1. **Lack of specific goals in cooperative establishment**: Many cooperatives were hastily established without clear, well-defined objectives, resulting in a lack of direction and effective planning for their long-term sustainability.

Table 7. Frequency distribution of cooperative support

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	93	93.0	93.0	93.0
	Yes	7	7.0	7.0	100.0
	Total	100	100.0	100.0	

2. **Absence of an effective economic organization structure**: Cooperatives often fail to establish a sound economic organizational framework, which undermines their ability to operate efficiently and achieve meaningful results in production and business activities.
3. **Insufficient land accumulation and capital contribution**: A lack of land consolidation and capital investment for expanding agricultural land has hindered the adoption of modern machinery and technology in production. As a result, many cooperatives function nominally rather than practically, lacking the resources and infrastructure needed to implement sustainable agricultural practices.
4. **Weak management skills and expertise**: The leadership in many cooperatives suffers from a lack of professional management skills and expertise. This gap in leadership capacity leads to an inability to effectively evaluate production performance and implement necessary changes for improvement.
5. **Subjective self-assessment of performance**: Although some cooperatives appear to perform well according to the Ministry of Planning and Investment's guidelines, these evaluations are often subjective and lack scientific rigor. Most cooperatives fail to assess their operational productivity in a systematic and data-driven manner, which diminishes the reliability of their performance assessments.

Given these challenges, establishing technology-driven cooperatives in coffee production is crucial for improving the economic prospects of coffee growers and strengthening the overall industry in Vietnam. This approach aligns with the state's strategic push for the development of the collective economy and digital transformation.

What technology will be applied for digital transformation in the coffee industry when building coffee cooperatives that differ from previous cooperative models? When building coffee cooperatives that differ from previous models, the digital transformation of the coffee industry will apply technologies that are vital for modernizing production processes. One crucial technology is Big Data. The foundation of digital transformation in any sector, including agriculture, is the digitization of data. Big Data has become essential in business and government activities, and its role in coffee production is no exception. Big Data tools will significantly change how knowledge is created in the coffee industry. The value of Big Data lies in the ability to identify valuable patterns by connecting individual data points, whether about a person, a group, or the structure of information itself. The quantity of data is a key feature of Big Data, but its true potential comes from the insights that can be derived by analyzing this data in various contexts (Harry, 2014).

The global economy has experienced significant transformations following the COVID-19 pandemic, with online shopping and digital supply chains increasingly dominating traditional business models. In response to these shifts, cooperatives and enterprises in Vietnam are adopting Blockchain technology to enhance the production and trade of coffee. As highlighted by F. Miatton and L. Amado, Blockchain, or decentralized ledger technology, represents a crucial advancement for ensuring the long-term sustainability of the coffee industry. By enabling traceability of coffee from origin to final product, Blockchain ensures complete transparency across the entire supply chain. This transparency allows consumers to track delivery times and gain clear insights into the quality and provenance of the coffee, thereby fostering trust. Furthermore, the openness provided by Blockchain is essential for guaranteeing fair compensation for farmers working on coffee plantations, ensuring that coffee products meet quality standards at every stage of production and distribution (Miatton and Amado, 2020).

While Big Data and Blockchain technology offer significant advantages for production and business in the era of information technology, there are also concerns associated with their implementation. Blockchain technology, in particular, raises issues such as the potential leakage of trade secrets, limited access to technology in remote areas, and high implementation costs. Additionally, the increased workload required for data entry and publication can complicate the process, particularly for older farmers who may find these technologies more challenging to adopt compared to traditional production methods.

To achieve these objectives, the Vietnamese coffee industry must adhere to the following criteria:

1. **Establishing clear goals for coffee cooperatives:** Coffee cooperatives must adopt modern technologies, such as Big Data and Blockchain, in production and business operations to meet the demands of the global coffee market. These goals should be developed using the SMART Goal framework, ensuring they are Specific, Measurable, Achievable, Relevant, and Time-bound (Fig. 2).
2. **Application of big data and blockchain technologies:** It is crucial to integrate Big Data and Blockchain technology into coffee production, as they offer distinct advantages over other technologies. Big Data, as demonstrated in agricultural studies, optimizes supply chain management, improves data classification (e.g., productivity, rainfall), and helps identify disease

patterns (Evstatiev and Evstatieva, 2021). Furthermore, Big Data can enhance enterprise productivity, reduce operating costs, and optimize supply chain management (Raguseo, 2018). It also provides a more accurate method for evaluating the effectiveness of digital marketing campaigns and optimizing marketing budgets (Mohieldin, 2021). Blockchain technology, as explored by Alamsyah *et al.* (2023), offers a model for tracing coffee supply chains, ensuring transparency and information flow among stakeholders, from farms to exports. This technology guarantees the traceability of coffee origins, bolstering trust in the supply chain.

The technology equipment will be recommended and supported by the technology production unit with backing from the government. Under Resolution No. 20, the state provides funding to offer management, science, and technology consultancy services to collective economic organizations based on their specific needs and contracts signed with service providers. This support aims to accelerate the digital transformation process. Additionally, the government will guide collective economic organizations in implementing projects that apply and enhance scientific and technological capabilities, fostering innovation. It will also facilitate access to medium- and long-term funding from the National Science and Technology Development Fund, as well as from ministries, sectors, and local authorities (The Central Executive Committee, 2022).

3. **Mobilizing cooperative farmers for production and business:** Legal contracts regarding capital contribution and land use for coffee cultivation should be established to encourage land accumulation, scale production, and apply modern technologies. Policies supporting land accumulation, such as Resolution No. 20, should facilitate large-scale agricultural production and ensure efficient business and processing services (The Central Executive Committee, 2022).
4. **Attracting Qualified Young Labor:** Coffee cooperatives must recruit young professionals with managerial and specialized qualifications, particularly for leadership positions and specialized departments. Human resource policies under Resolution No. 20 should support attracting talented managers and scientists to work in cooperatives. The government should provide funding for training these officials at universities with relevant majors (The Central Executive Committee, 2022).
5. **Building a robust organizational structure for cooperatives:** Coffee cooperatives should develop a comprehensive organizational structure with specialized departments for various functions, including production, business operations, technology management, product development, marketing, finance, and logistics. This structure should mirror that of agricultural-industrial enterprises, facilitating efficient operations across the entire value chain. The cooperative's operational model should integrate modern technologies into its business processes (Fig. 3).

Collective economic organizations should have access to financing on par with other economic entities, supported by mechanisms that enhance financial capacity and market access. The Cooperative Development Support Fund should assist cooperatives in securing funds at preferential interest rates and provide post-investment support to ensure transparency and accountability in investment decisions (The Central Executive Committee, 2022).

The effectiveness of coffee cooperatives' activities will reflect both the development of the coffee sector and the success of government policies aimed at fostering cooperative economies and supporting digital transformation. To assess the effectiveness of these activities, economists often employ the Cobb-Douglas production function. However, the Cobb-Douglas function does not adequately capture the institutional factors influencing the efficiency of cooperatives in the coffee sector. Thus, the production function theory proposed by Russian economist O.V. Inshakov offers a more comprehensive framework.

Inshakov's production function, expressed as Q = F(A, T, Rn, Ins, O, Inf), includes six factors:

- A (Human Resources): Labor, including intelligence, physical attributes, and creativity.
- T (Technology and Techniques): The machinery, tools, and production techniques employed.
- Rn (Natural Resources): Resources such as land and environmental factors that support production.
- Ins (Institutional Factors): Policies, government support, and resources for cooperatives.
- O (Organization): The structure of production and business activities within the cooperative.
- Inf (Information): The market reflection of the products produced, impacting sales and consumption.

The factors related to resource creation, denoted as Tf (A, T, Rn), transform the cooperative's resources into coffee products. The factors related to production outcomes, denoted as Ta (Ins, O, Inf), reflect the transactions that occur within the market. Therefore, the production function can be simplified as Q = F(Tf, Ta), as proposed by Inshakov (2003). Given the significant

Fig. 2. Diagram of goals for establishing a coffee cooperative

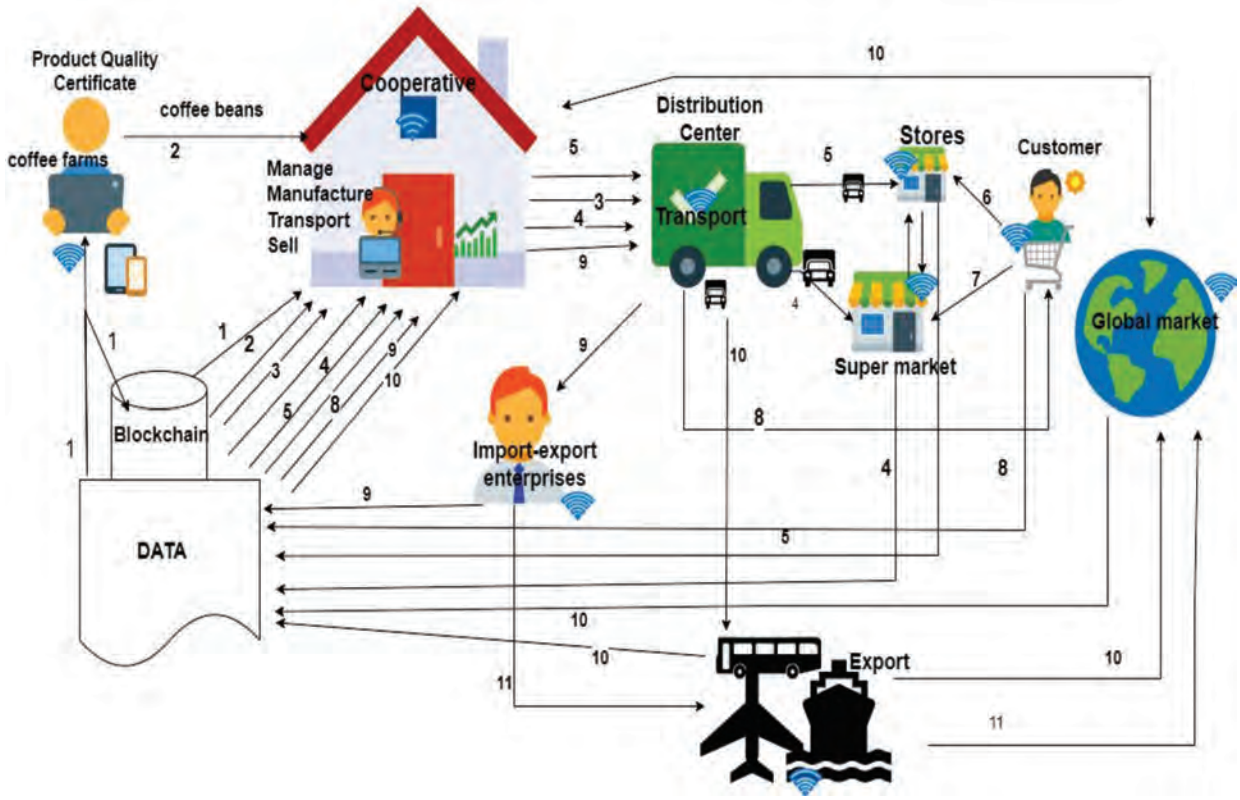


Fig. 3. Diagram of the operational model for a technology-integrated coffee cooperative

support from state policies and the integration of digital technologies, this production function is highly applicable to coffee cooperatives in Vietnam. It captures both the resources and institutional support necessary for the cooperative economy's development and digital transformation.

Note: The sequence and operational methods of the Technology Application Cooperative in Big Data and Blockchain for production and business operations, as depicted in the diagram, are as follows:

1. ***Data Input in Production****: Production data is entered into the system. Thanks to Big Data and Blockchain integration, all production data across the fields is accessible to every part of the cooperative via the information system. Blockchain allows customers to trace product information from the field to production and ultimately to the consumer.*
2. ***Harvesting and Transport to Factory****: Harvested coffee beans are transported to the factory, where relevant information is recorded and displayed on the information system.*
3. ***Production Process and Distribution****: After the production processes at the factory, finished products are sent to the cooperative's distribution center, with information recorded and displayed on the system.*

4-5. ***Orders from Supermarkets and Stores****: Business customers (supermarkets or stores) place orders, and the information is transmitted to both the cooperative and distribution center systems. Thanks to Big Data, transportation and delivery are transparent for both the cooperative and customers via the cooperative's application.*

6-7. ***Individual Customer Purchases****: Individual customers purchasing cooperative coffee products at stores or supermarkets can access product details through QR codes, enabled by Blockchain technology.*

8. ***Customer Orders through Application****: When individual customers place orders via the cooperative's application, the information is transmitted to the cooperative's system. The distribution center's delivery department coordinates and completes the order.*

9,11. ***Export Orders****: Export customers in Vietnam place orders, with coffee export enterprises completing contracts and online payments. The order information is transmitted to the cooperative through the system. The transportation center then manages logistics to the export delivery port. Throughout the international transportation and delivery process, the status of the goods can be tracked via the information system.*

10. *International customers, including both enterprises and individuals, place orders and complete contracts and online payments. The order information is transmitted to the cooperative through the system, and the transportation center manages logistics to the export delivery port. The entire international transportation and delivery process can be tracked through the information system.*

CONCLUSION

The Vietnamese coffee industry, predominantly driven by small-scale farmers, plays a pivotal role in the nation's economy but faces multifaceted challenges. These include limited access to modern technology, financial constraints, and inefficient cooperative management structures. This study highlights the critical importance of integrating advanced technologies, such as Big Data and Blockchain, into cooperative models to enhance productivity, traceability, and economic sustainability. The findings demonstrate that technology adoption significantly boosts yield and labor productivity while addressing key challenges like water efficiency, market access, and quality assurance. However, for these technological interventions to be successful, robust governmental support, effective training programs, and cohesive organizational frameworks are essential. Policies emphasizing digital transformation, land accumulation, and skilled workforce development will be instrumental in fostering a resilient and competitive coffee sector. Strengthening the operational capacity of cooperatives and ensuring equitable access to resources for smallholders will further enhance Vietnam's position in the global coffee market. Future research should focus on evaluating the long-term impacts of these technological and cooperative models on the socio-economic well-being of smallholder farmers and the broader industry. By the use of innovation and collective effort, Vietnam's coffee industry can achieve sustainable growth and secure its legacy as a global leader in coffee production.

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Authors' contribution

Conceptualization of research work and design of experiment (TTDH & LVP), Execution of field/lab experiments and data collection (TTDH), Analysis of data and interpretation (TTDH & LVP), Preparation of manuscripts (TTDH & LVP).

Conflicts of interest

Authors declare that they have no conflicts of interest.

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