# A pathway to digitising Vietnamese mango value chains to facilitate international export growth

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Received 30 August 2024; revised 10 September 2024; accepted 11 November 2024

***Abstract:***

**Recent growth in global demand for fresh mangoes has created an attractive export opportunity for Vietnam's mango industry. However, accessing international markets requires adherence to stringent quality, safety, and traceability standards. This article highlights three key areas where digital information technology (DIT) can enhance the efficiency of Vietnam's mango export value chain to meet these requirements. First, DIT can improve communication and the sharing of market information among stakeholders while simultaneously enhancing quality, safety, and traceability standards. Second, digital technology can automate various activities within the value chain, creating opportunities to reduce production costs and improve product uniformity. Finally, it can facilitate the recording and tracking of stakeholders' activities to ensure compliance with traceability requirements. However, the adoption of digital technology by mango farmers remains limited due to the need for substantial investment capital, a lack of DIT-related skills, and the traditional absence of farm record-keeping for improving management practices. This study found that both financial and non-financial government support programmes are essential for the widespread adoption of digital technology across the mango value chain. These programmes can provide the necessary resources and training to develop a more efficient and competitive mango export value chain.**

***Keywords:*** **digital information technology, global market requirements, Vietnam's export mango value chains.**

***Classification numbers:*** **2.1, 2.2**

## 1. Introduction

Mangoes (*Mangifera indica L.*) rank among the most widely consumed fruits worldwide, with global consumption experiencing significant growth due to increasing income levels and evolving dietary habits [1]. Consequently, production and exports are rising, particularly from Asia, with a projected annual growth rate of 3.3% from 2020 to 2030 [2]. Southeast Asia, as the genomic home of mangoes, is home to major producers such as India, China, and Thailand [3]. Despite this, Vietnam is currently ranked only tenth in global production, accounting for approximately 3% of total world output [4].

At present, Vietnam exports mangoes to 53 countries and territories. While Vietnamese mangoes are exported to markets such as the US, the European Union (EU), and Japan, export volumes remain modest. China is the most significant export market, representing over 83% of the market share and contributing USD 151.8 million to the total mango export value. Other importers of Vietnamese mangoes include Russia, Papua New Guinea, the US, South Korea, EU, Australia, and Japan (Fig. 2). In 2020, the global export value of mango products reached USD 12.3 billion; however, Vietnam's export turnover was approximately USD 180.8 million, accounting for just over 1.5% of the global market [5].

Over the past three years, mango production volumes in Vietnam have steadily increased, accompanied by significant growth in export volumes and revenues. The Vietnamese government aims to expand mango cultivation from 87,000 to 140,000 ha by 2030, with the goal of positioning Vietnam among the top 15 organic-producing countries by the same year [6]. Since mangoes are predominantly consumed fresh, compliance with general quality standards, food safety regulations, and traceability requirements mandated by importing countries is essential for export success [7-11]. This includes achieving organic certification and ensuring adherence to international quality and traceability standards. The government has a critical

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role in issuing specific production unit codes (PUCs) for mango-growing areas designated for export markets. These codes validate the authenticity of growing regions by certifying their compliance with established quality standards, ensuring that products meet the requirements set by importing countries. As of now, the Vietnamese Ministry of Agriculture and Rural Development (MARD) has issued 845 PUCs for mango-exporting regions nationwide [6]. Consequently, product attributes such as food safety, quality standards, and traceability should be prioritised as key information to be exchanged among stakeholders in the value chain to ensure effective compliance.

The adoption of DIT, such as smartphone-based tools for weather monitoring, farm management recording, marketing information, and traceability data, could enable actors throughout the mango value chain to meet these requirements. However, practical implementation of DIT in agribusiness value chains remains a significant challenge [12-14].

The research is guided by the following questions: (1) How do current information exchange practices and communication flows among mango value chain actors influence their capacity to adhere to international market requirements?; (2) What are the perceived benefits of DIT adoption for mango farmers and other value chain stakeholders in the context of international market compliance?; (3) What constitute the principal constraints and challenges impeding the effective adoption and implementation of DIT within the Vietnamese mango value chain?; (4) How can governmental intervention in the mango industry effectively facilitate the application of DIT to enhance traceability and food safety within mango export value chains?

By focusing on two exemplary mango value chains in Son La and Dong Thap provinces, this research aims to propose a possible pathway for improving the mango industry's adoption of DIT that will build its capability to meet the international market requirements.

## 2. Literature review

While opportunities for Vietnamese mango production are evident, total factor productivity in agriculture is declining. The industry is characterised by small landholdings, institutional constraints, reliance on low-skilled labour, and traditional production methods [15]. Decades of agricultural research have identified several specific challenges, including poor agronomic practices and farm business management, a lack of collaborative marketing to achieve economies of scale, inefficient supply chains [16, 17], and an inability to comply with the requirements of modern international markets in and non-compliance with modern international standards for quality, food safety, phytosanitary measures, and provenance [18]. Addressing these issues is critical for enhancing the competitiveness of Vietnamese mangoes in the global market.

The World Bank has identified information gaps within the agricultural value chain as a primary contributor to high transaction costs and low productivity in Vietnamese agriculture. These issues arise primarily from the lack of effective decision-support systems and the inability of key stakeholders to access necessary information, address challenges, and communicate effectively within the value chain [15]. However, Vietnam holds significant potential for digital transformation, given that it has the third most affordable digital access globally. Additionally, 90% of farmers own mobile phones, and 42% have access to 3G or 4G networks [19].

Various proposals have advocated the adoption of DIT, such as blockchain technology, to enhance traceability, food safety, and food authenticity in agriculture [14, 20]. Studies have also shown that applying DIT in farming can boost labour productivity and increase transparency within the value chain [21, 22]. Digital green value co-creation behaviour has been identified as a tool for agribusinesses to achieve sustainable ecological advantages in today's complex market environment [23]. However, despite its potential, concerns have been raised about the challenges posed by the heterogeneity of the agrifood sector, infrastructure limitations, small farm scale, and resource constraints [13, 24]. Globally, blockchain technology is in its infancy, with few established standards and significant challenges related to transaction risks, high costs, interoperability, and scalability [25-28].

Addressing these challenges requires a multi-faceted response from the government, with digital literacy identified as the first stage of digital transformation in agriculture [29]. From 2015 to 2017, the Vietnamese government introduced policies focused on developing Industry 4.0 through initiatives such as Decision No. 392/QD-TTg (2015), which outlined a vision for the digital transformation of the agricultural economy, Decision No. 149/QD-TTg (2016), which focused on infrastructure development, and Directive No. 16/CT-TTg (2017), which aimed to strengthen progress in this domain.

Although digital transformation offers a promising pathway to improving value chain efficiency, small farmers in developing countries face significant challenges during this process. The World Bank [15] identified that this involves the level of knowledge and skills of the workforce in both technical and soft skills. Regarding this condition, there has been a shortage of employees with professional and technical training in the Vietnam agribusiness [19]. The lack of skills has made agricultural labour productivity relatively low.

A study on value-based decision-making [30] identified that a behavioural shift in traditional farmers' values combined with reputational enhancement and resourcing is required to achieve a change in their self-perception regarding professional-oriented values [23]. Others have highlighted the cost-benefits of focusing on digital literacy and providing the resources to access the internet [31, 32] and the ability to recognise opportunities and accept the risks associated with pursuing the opportunity [33-36].

However, beyond that, there appears to be a widespread lack of understanding of how digitisation has value for smallholders in agribusiness [37]. This is likely because, at the current stage, available technologies are largely limited to smartphone applications, with few specifically designed for agriculture [29].

These imperatives coupled with the low starting base for commencing the transition raise questions about the status of farm labour competencies, how can technology assist, what technologies are appropriate, the scope of competencies needed, and the training priorities [13, 15, 22].

This article seeks to address the question "How can the Vietnamese Government support the application of digital information technologies to improve traceability and food safety in selected mango export value chains in two provinces in northwest and southern Vietnam?" The following sections describe how this investigation's results and findings provide a policy pathway for the Vietnamese Government to develop the industry's capacity to expand international exports of mango products.

## 3. Methodology

### *3.1. Site selection*

The MARD assisted in selecting two distinct but significant production regions for this investigation: Dong Thap province, located 165 kilometres southwest of Ho Chi Minh City, is a leading producer in the south, while Son La province, situated on the Moc Chau plateau in northwest Vietnam, is a major cool-temperate green mango production area.

Mangoes are predominantly cultivated in the Mekong River delta, which accounts for approximately 48% of the total mango cultivation area in Vietnam. Among these, Dong Thap province is identified as a critical locality, with 13,000 ha under cultivation and an annual output of nearly 113,000 tonnes. Mangoes are cultivated year-round in Dong Thap, with the fruit carefully covered to ensure safety and an appealing appearance. The province has registered 62 PUCs for export to China, covering 3,927 ha, and 45 PUCs for export to other developed countries, encompassing 988 ha [38].

Similarly, the Plant Protection Department of the MARD has granted 99 PUCs to Son La province, covering over 1,400 ha. Most of the mangoes produced in this region comply with VietGAP, GlobalGAP, and organic production standards.

Vietnam cultivates a wide variety of mangoes, with the most popular commercial varieties being Cat Hoa Loc, Cat Chu, and Green Taiwanese. In Son La, Green Taiwanese mangoes are the predominant variety, with an average cultivation area of 0.71 ha per household. In contrast, the cultivation area for Green Taiwanese mangoes in Dong Thap is significantly smaller, averaging 0.06 ha per household. In Dong Thap, Cat Chu is the primary variety, with an average cultivation area of 0.34 ha per household, followed by Cat Hoa Loc, with 0.14 ha per household.

Mango production in Vietnam has gradually increased in recent years, reaching 938.2 thousand tonnes in 2021 [37]. However, climate-related risks, particularly in Son La, have increasingly impacted production. Approximately 76.52% of respondents in Son La reported experiencing production losses due to adverse weather and crop failures over the past three years. Despite this, income from mango cultivation contributes significantly to household livelihoods, accounting for 55.10% of the average household income in Son La and 75.97% in Dong Thap [39]. This indicates a higher dependency on mango production in Dong Thap compared to Son La.

### *3.2. Research methods*

The study utilised a Participatory Action Research (PAR) approach, encompassing a desk study of relevant literature on mango production, in-depth interviews with mango experts, focus group discussions in each province with 10-12 key stakeholders, and face-to-face survey interviews with 150 farmers in each province.

A desktop analysis was conducted on food safety regulations for four major potential markets: China, South Korea, Australia, and the United States. This was followed by in-depth interviews with representatives from the Agri-Trade Promotion Centre (MARD) and three mango exporters from Dong Thap and Son La provinces to understand the challenges of compliance with these regulations.

The focus group discussions were employed to elicit diverse viewpoints and assess their relative efficiency in capturing a wide range of perspectives from value chain stakeholders [40]. The focus group membership was selected using stratified purposeful sampling [41, 42], a non-probability sampling method that divides the sampling frame into strata to create relatively homogeneous sub-groups, from which a purposeful sample is drawn. The strata

included representatives from local government authorities, farmers' unions, cooperatives, collectors (aggregators), and exporters. Discussion topics were developed in collaboration with MARD and industry stakeholders.

Survey interviews were conducted with 298 respondents, 148 from Son La and 150 from Dong Thap. Due to literacy concerns, a member of the research team completed the pre-tested survey instrument on behalf of the respondents. Participants were selected using a stratified random sampling method based on local authority records, considering criteria such as location, experience, scale of operation, participation in export production, and technological engagement. The survey instrument was developed in collaboration with stakeholders. Female labourers accounted for an average of 20.81% of respondents in both areas, although women in Vietnam generally do not head households or make production decisions. This is about half the reported rate of female labour participation in agricultural activities overall in Vietnam [39].

The data collected were used to develop a Theory of Change through a large systems change approach [43] with our PAR methods [44, 45]; adopting a multi-strategy approach to designing change which employed two of the four strategies identified by [43]: 'Co-creating change' and 'Supporting Change'. A logic model was constructed using problem and objective tree analysis, followed by listing activities to achieve the objectives. Causal connections were then developed from these activities to project outputs, outcomes, impacts, and strategic impacts, with identified assumptions and external risks summarised into a pathway diagram for ease of interpretation.

We then analysed the study's results using [46] "Policy Platforms" framework, which has been influential in regional innovation systems policy in Europe, to assist the development of 'constructed advantage' for Vietnam's Mango Industry. This framework supports the development of 'constructed advantage' for Vietnam's mango industry by leveraging existing social capital to facilitate product innovation, local governance mechanisms, knowledge infrastructure, and community and cultural readiness for innovation. This involves:

• Proactively 'constructing' economic competitiveness in regions, promoting inter-firm interactions, integration of knowledge generation, both local and global business networks.

• Developing governance mechanisms using multilevel governance of stakeholder interests, policy-support for innovators, enhanced budgets for research and vision-led policy leadership.

• The collaboration of knowledge-based organisations in constructing advantage in regions including universities, public sector research, public sector agencies, and NGOs focused on problem-solving.

• Community and culture: community and a public cultural orientation toward pro-activity and innovation using communication techniques [46].

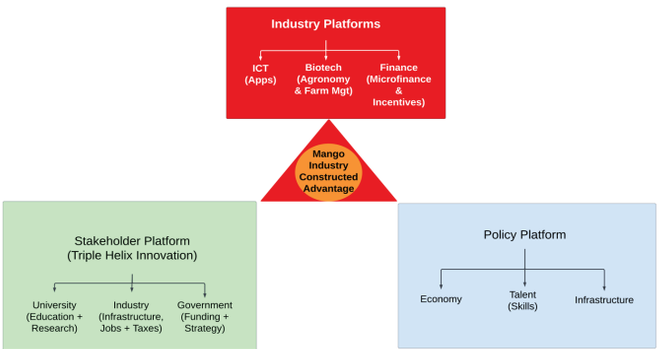


**Fig. 1. Policy platforms adapted for Vietnam's export mango industry** [46].

Finally, the study's results were presented to 35 processors/exporters, local government officers, and academics in a consultation workshop for critical feedback. The workshop included six presentations by chain stakeholders regarding potential pathways to improve the capacity and skills of workers in mango farms.

Microsoft Excel was used for data management, while SPSS software was employed for descriptive and comparative analyses and to conduct significance tests on the perspectives of respondents across provinces, genders, and ethnicities.

## 4. Results

Typically, the Mango Value Chain actors engage across three exchange domains: the Product Flow, the Information/Communication Flows, and the Governance Relationships, all of which are centred on delivering value to consumers (Fig. 2). Product Flows involve the physical exchange of goods which in the mango chain flow only towards the Processor/Exporters. The Information/Communication Flows are two-way and usually involve the management of the key supply risk concerns of the Aggregators and the Processor/Exporters. Finally, the third flow is the exchange related to the chain's coordination which is achieved using formal and informal (relational) contracting and Incentives/Disincentives. Ultimately, it is consumer demand for specific value attributes in the product that drives the chain's efficiency and effectiveness. This consumer-driven pull ensures optimal value delivery throughout the chain [47].

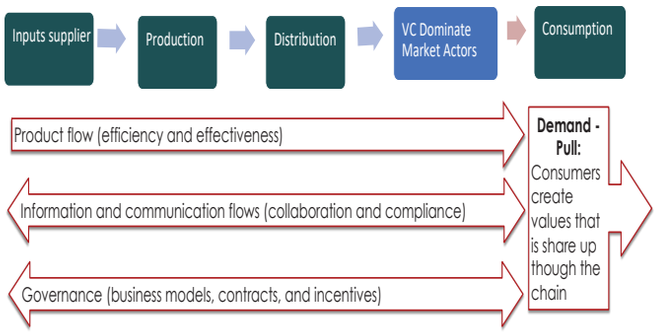


**Fig. 2. Domain of exchanges among actors in the mango value chain.** Source: Own compilation from the literature [16, 46], interviews and FGDs.

The following sections primarily present findings related to Information/Communication Flows, as these are the areas where DIT can have the greatest impact. We also discuss results related to Production and Product Flows, given that digital tools provided to farmers and aggregators can significantly improve data collection. Such advancements can support the modernisation of mango supply chains, ensuring compliance with international frameworks for quality, food safety, and traceability. This alignment with consumer-driven values can ultimately lead to the upgrading of mango value chains.

### *4.1. Information perceived by mango farmers*

The survey revealed significant disparities in demographics, education, and training opportunities between the two study regions. For instance, ethnic minorities represented 81.76% of participants in Son La, with most identifying as Thai (a minority ethnic group) (Table 1). By contrast, only Kinh (the ethnic majority) participants were recruited in Dong Thap. Additionally, the proportion of farmers with a high school education or higher was low, at just 26.84% across the sample. Dong Thap had a higher rate of educated farmers compared to Son La, indicating that a lack of formal education may influence farmers' awareness and behaviour towards adopting digital technologies.

**Table 1. Overview of the survey (n=298).**

| Proportion of | Percentage (%) | | |
|---|---|---|---|
| | *Average* | *Dong Thap* | *Son La* |
| Female respondents | 20.81 | 6.67 | 35.14 |
| Ethnic minority respondents | 40.61 | - | 81.76 |
| Female respondents with high school education and above | 26.84 | 35.33 | 18.24 |
| Household income from mango production | 55.10 | 75.97 | 33.95 |

Source: Own compilation from the surveyed data.

Training opportunities were also unevenly distributed. Farmers in Dong Thap were more likely to have participated in training sessions compared to those in Son La, both in production (87.3% versus 58.1%) and marketing (15.3% versus 5.4%) (Table 2). However, these training sessions primarily focused on production practices, with limited coverage of supply chain information or DIT-related content. Farmers in Son La were often unaware of the types of training courses available, particularly those related to marketing.

**Table 2. Mango production and marketing training experiences (n=298).**

| | | Province | | | | Gender of household head | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Dong Thap* | | *Son La* | | *Male* | | *Female* | | | |
| | | *Count* | *%* | *Count* | *%* | *Count* | *%* | *Count* | *%* | *Count* | *%* |
| 1. Training on growing mango | Yes | 131 | 87.3% | 86 | 58.1% | 208 | 73.5% | 9 | 60.0% | 217 | 72.8% |
| | No | 19 | 12.7% | 62 | 41.9% | 75 | 26.5% | 6 | 40.0% | 81 | 27.2% |
| • Production, harvest and post-harvest techniques | Yes | 125 | 96.9% | 79 | 100.0% | 196 | 98.5% | 8 | 88.9% | 204 | 98.1% |
| | No | 4 | 3.1% | - | | 3 | 1.5% | 1 | 11.1% | 4 | 1.9% |
| • Plant protection (pest management) | Yes | 21 | 16.3% | 19 | 24.1% | 37 | 18.6% | 3 | 33.3% | 40 | 19.2% |
| | No | 108 | 83.7% | 60 | 75.9% | 162 | 81.4% | 6 | 66.7% | 168 | 80.8% |
| • Plant nutrition and fertilisation | Yes | 10 | 7.8% | 13 | 16.5% | 22 | 11.1% | 1 | 11.1% | 23 | 11.1% |
| | No | 119 | 92.2% | 66 | 83.5% | 177 | 88.9% | 8 | 88.9% | 185 | 88.9% |
| • Post-harvest techniques (pre-processing, preservation, processing) (organic/ GAP standards) | Yes | 5 | 3.9% | 1 | 1.3% | 6 | 3.0% | - | | 6 | 2.9% |
| | No | 124 | 96.1% | 78 | 98.7% | 193 | 97.0% | 9 | 100.0% | 202 | 97.1% |
| • Agri- standards (Organic, VietGAP, GlobalGAP, Safe) | Yes | 60 | 46.5% | 1 | 1.3% | 60 | 30.2% | 1 | 11.1% | 61 | 29.3% |
| | No | 69 | 53.5% | 78 | 98.7% | 139 | 69.8% | 8 | 88.9% | 147 | 70.7% |
| • Traceability (Production Unit Code - PUC, bookkeeping - diary, VietGAP or GAP/ organic - standards) | Yes | 71 | 55.0% | 1 | 1.3% | 70 | 35.2% | 2 | 22.2% | 72 | 34.6% |
| | No | 58 | 45.0% | 78 | 98.7% | 129 | 64.8% | 7 | 77.8% | 136 | 65.4% |
| • IFAD | Yes | 2 | 1.5% | - | | 2 | 1.0% | - | | 2 | 0.9% |
| | No | 127 | 96.9% | 79 | 91.9% | 197 | 94.7% | 9 | 100.0% | 206 | 94.9% |
| 2. Mango business training | Yes | 23 | 15.3% | 8 | 5.4% | 31 | 11.0% | - | | 31 | 10.4% |
| | No | 127 | 84.7% | 140 | 94.6% | 252 | 89.0% | 15 | 100.0% | 267 | 89.6% |
| • E-commerce (online marketing, e-sales, IFAD) | Yes | 11 | 52.4% | - | | 11 | 47.8% | - | | 11 | 47.8% |
| | No | 10 | 47.6% | 2 | 100.0% | 12 | 52.2% | - | | 12 | 52.2% |
| • Marketing, sale, negotiation | Yes | 16 | 76.2% | 2 | 100.0% | 18 | 78.3% | - | | 18 | 78.3% |
| | No | 5 | 23.8% | - | | 5 | 21.7% | - | | 5 | 21.7% |
| • GAP & IFAD | Yes | 4 | 19.0% | - | | 4 | 17.4% | - | | 4 | 17.4% |
| | No | 17 | 81.0% | 2 | 100.0% | 19 | 82.6% | - | | 19 | 82.6% |
| • Business economics and business management (+GAP) | Yes | 13 | 61.9% | - | | 13 | 56.5% | - | | 13 | 56.5% |
| | No | 8 | 38.1% | 2 | 100.0% | 10 | 43.5% | - | | 10 | 43.5% |

Source: Own compilation from the surveyed data.

Unfortunately, women often have fewer opportunities to participate in training programmes that transfer scientific and technical knowledge [8-11] (also see [48]). In the survey, 60% of female household heads participated in mango production training sessions, compared to 73.5% of male household heads. None of the female participants attended business training courses, while 11% of men did. This gender disparity is consistent with broader trends in Vietnam, where women are often disadvantaged in accessing agricultural jobs and extension programmes. Consequently, women's economic contributions in farming are frequently constrained.

The average area of a farm household under mango cultivation in this study is relatively small, at 0.9 ha. The smallest area reported is 0.1 ha, while the largest is 5 ha. Mango-growing households in Dong Thap generally operate on smaller plots compared to those in Son La.

As highlighted in the introduction, key product attributes-food safety, quality standards, and traceability-should constitute the core elements of communication among stakeholders within the value chain. However, except for quality standards, survey results indicate that most mango farmers lack sufficient understanding of the diverse aspects required for export markets. Notably, farmers from Son La exhibit a slightly higher level of awareness compared to their counterparts in Dong Thap, although traceability and export market pricing remain the least understood topics across both provinces (Table 3). These findings align with the training experiences reported by mango labourers (Table 2).

**Table 3. Mango farmers' awareness of market requirements (n=298).**

| Mango farmers' awareness (%) | Son La | Dong Thap | Average |
|---|---|---|---|
| Export market prices | 37.8 | 53.3 | 45.6 |
| Affordable prices | 73.7 | 46.0 | 59.8 |
| Importance of the stable supply quantity | 34.5 | 43.3 | 38.9 |
| Market requirements for quality standards | 85.8 | 66.7 | 76.2 |
| Market requirements for varieties | 71.0 | 45.3 | 58.1 |
| Market requirements for food safety | 56.1 | 52.0 | 54.0 |
| Market requirements for traceability | 31.8 | 44.7 | 38.2 |
| Provincial average | 55.8 | 50.2 | |

Source: Own compilation from the surveyed data.

Farmers ranked market information in terms of importance as follows: (1) stable supply quantity, (2) traceability, and (3) food safety. Remarkably, 'prices' ranked fifth out of six categories, suggesting that farmers do not view pricing as a critical factor in their marketing and production decisions. This indicates that while farmers recognise the importance of market requirements, their access to such information requires significant improvement.

Limited communication with other value chain actors severely restricts mango growers' access to market-related information. Respondents overwhelmingly reported that direct, face-to-face communication is the most effective method. This approach is predominantly used to communicate with traders (65.44%), other farm workers (57.72%), and local officials (19.8%). Face-to-face communication was favoured for its clarity, friendliness, and the ability to exchange detailed information. However, less than 50% of communication on food safety and traceability requirements occurs through this method.

Digital communication tools, such as Zalo or Facebook, are also used but represent a relatively small share of overall value chain communications. There are notable differences in the perceived effectiveness of these tools between regions. In Dong Thap, only 36.7% of respondents considered e-communication effective, compared to 82.4% in Son La. Thai ethnic households, which are more prevalent in Son La, tend to use digital communication more frequently than Kinh households, potentially explaining the regional differences.

Additionally, the percentage of farmers who record and store information related to mango production and trading is low, ranging from 15.4% to 35.2%. Farmers in Dong Thap are more likely to record information compared to those in Son La. However, the use of computers or smart devices for recording purposes is minimal, at only about 1% of the total sample. While over 50% of farmers believe that recording and storing information is necessary, this practice remains uncommon in reality.

### *4.2. Information perceived by other mango value chain stakeholders*

Each stage of the supply chain has distinct information needs (Table 4), as identified through in-depth interviews, focus group discussions, and a consultation workshop. These needs can be categorised into three primary domains:

Domain 1: Farmers' need for marketing price, volume, quality assurance standards and time scheduling information;

Domain 2: Exporters' need for yield, volume information plus quality assurance audit data for food safety, traceability, provenance compliance plus expected harvest dates;

Domain 3: Supply chain aggregators who need yield, volume information plus quality assurance audit data for food safety, traceability, provenance compliance plus expected harvest dates.

**Table 4. Mango value chain actor's needs for external information.**

| Input suppliers | Mango farmers | Cooperatives | Collectors | Exporters | Consumers |
|---|---|---|---|---|---|
| Quantity of mango production in the market area | Market price - export<br>Export demand volume<br>Export product quality standards<br>Market price - domestic | Member's potential production<br>Post harvest and processing technique<br>Demand by grade/ quality<br>Production volume X time | Export product quality standards<br>Volume demand for different mango grades by exporters<br>Price by grade<br>Compliance with quality assurance standards<br>Production volume X time | Potential market demand for export mangos<br>Expected production yield<br>Product attributes (quality, food safety traceability)<br>Probable yield<br>Compliance with quality assurance standards | Product attributes (quality, food safety, traceability, provenance)<br>Price |

Source: Own compilation from the interviews, FGDs and the consultation workshop.

Mango exporters are the dominant actors in the value chain, possessing substantial knowledge of market requirements (Table 5). Exporters negotiate directly with key producers (e.g., cooperatives and large farms in Dong Thap) and multilevel collectors (e.g., district- or communal-level collectors) to reach smaller farmers, particularly in Son La. However, formal contracts that clearly outline market requirements are uncommon, especially with small-scale producers. Instead, verbal agreements are widely used, increasing the likelihood of non-compliance with market standards at the production level.

Cooperatives often play a critical role in aggregating outputs from member farmers and managing sales and market requirements with larger collectors or export companies. However, their capacity is limited; they primarily act as intermediaries rather than exporters. This limitation is particularly evident in remote areas like Son La, where export treatments (e.g., irradiation for the US and Australia, vapour heat treatment or hot water treatment for Japan and South Korea) must be performed in distant cities such as Hanoi or Ho Chi Minh City.

During field visits, a notable exception was observed in Dong Thap, where one exemplary cooperative had established annual contracts with mango exporters. This cooperative outsourced marketing activities to the exporters' teams, offering a 5-10% commission. By doing so, the cooperative gained timely access to market requirements and effectively planned its production and marketing activities.

**Table 5. General requirements of the export market for mango fresh fruit.**

| Requirements | Meaning | Criteria relating to fresh mango product | Import assessment criteria | Compliance evidence |
|---|---|---|---|---|
| Food safety | Food safety refers to the handling, storing, and preparing food to prevent infection and to help ensure that food contains enough nutrients for a healthy diet. | Pesticide residues and contaminants | A set of maximum residue levels (MRLs) for pesticides | Certificate of plant quarantine |
| | | | Lead contamination and cadmium MRLs | |
| | | | Microbiological contamination (for fresh-cut mango) | |
| | | IPM | Good agricultural practices | GAP or other certificates |
| | | Phytosanitary | The product has been treated effectively to ensure freedom from fruit flies *Tephritidae spp* and was produced in a fruit fly free area. | Phytosanitary certificates with traceability information |
| Food quality standards | Food quality is the combination of food product attributes or characteristics that have significance in determining the degree of acceptability of the product to a consumer. Food standards are the mandatory national regulatory requirements that cover food safety and handling, food labelling and advertising and food composition, including contaminants, residues and additives. | Mangoes in the exported class must be of good quality and within the permissible tolerance levels as specified in the *International Standards for Fruit and Vegetables for Mangoes* [2]. | In no case may the defects affect the fruit flesh, the general appearance of the produce, the quality, the keeping quality and the packaging presentation. | Classification on the packing label |
| Traceability | Ability to follow the movement of a food product through specific stages of production, processing, and distribution along the supply chain. | A digital traceability system with labelling in mango fruit throughout the supply chain from producers to the consumer. A farming information system is essential as well as whole-of-supply chain transparency. | A digital traceability system providing evidence of safety, authenticity and provenance ideally combined with a consumer digital app providing traceability information. | Labelling and audit data |

Source: Own compilation from the literature, interviews, FGDs and the consultation workshop.

### *4.3. Constraints to adopting DIT for expanding export production*

In various interviews and focus group discussions, many value chain stakeholders emphasised the growing importance of adopting DIT for mango exports. They also recognised its increasing relevance in meeting the rising quality standards demanded in domestic markets. However, many mango farmers were unable to perceive the benefits of applying digital technologies. A significant proportion of farmers - 71% in Dong Thap and 74% in Son La - considered this a moderate to extremely serious issue (Table 6). The survey also highlighted

several barriers to DIT adoption, which were of significant concern to the majority of respondents. These barriers include: lack of availability and quality of internet connection; too costly for procurement and maintenance, service; lack of confidence in using technology of employees; difficulty accessing support and training; and concerns about privacy, security, and data security (Table 6).

**Table 6. Main problems when applying digital information technology technology (n=298).**

| Adoption barrier(s) | | Dong Thap | | Son La | |
|---|---|---|---|---|---|
| | | *Count* | *%* | *Count* | *%* |
| Lack of availability and quality of internet connection | 0 = Not at all | 22 | 14.7% | 35 | 23.6% |
| | 1 = Very minor problem | 13 | 8.7% | 32 | 21.6% |
| | 2 = Minor problem | 14 | 9.3% | 21 | 14.2% |
| | 3 = Moderate problem | 34 | 22.7% | 37 | 25.0% |
| | 4 = Serious problem | 33 | 22.0% | 15 | 10.1% |
| | 5 = Extremely serious problem | 34 | 22.7% | 8 | 5.4% |
| Too costly for procurement and maintenance, service | 0 = Not at all | 18 | 12.0% | 16 | 10.8% |
| | 1 = Very minor problem | 8 | 5.3% | 8 | 5.4% |
| | 2 = Minor problem | 18 | 12.0% | 17 | 11.5% |
| | 3 = Moderate problem | 40 | 26.7% | 30 | 20.3% |
| | 4 = Serious problem | 36 | 24.0% | 35 | 23.6% |
| | 5 = Extremely serious problem | 30 | 20.0% | 42 | 28.4% |
| Lack of confidence in using technology of employees | 0 = Not at all | 13 | 8.7% | 8 | 5.4% |
| | 1 = Very minor problem | 9 | 6.0% | 25 | 16.9% |
| | 2 = Minor problem | 6 | 4.0% | 22 | 14.9% |
| | 3 = Moderate problem | 35 | 23.3% | 30 | 20.3% |
| | 4 = Serious problem | 42 | 28.0% | 36 | 24.3% |
| | 5 = Extremely serious problem | 45 | 30.0% | 27 | 18.2% |
| Difficulty accessing support and training | 0 = Not at all | 18 | 12.0% | 9 | 6.1% |
| | 1 = Very minor problem | 17 | 11.3% | 24 | 16.2% |
| | 2 = Minor problem | 15 | 10.0% | 24 | 16.2% |
| | 3 = Moderate problem | 36 | 24.0% | 35 | 23.6% |
| | 4 = Serious problem | 32 | 21.3% | 30 | 20.3% |
| | 5 = Extremely serious problem | 32 | 21.3% | 26 | 17.6% |
| Concerns about privacy, security, and data security | 0 = Not at all | 21 | 14.0% | 22 | 14.9% |
| | 1 = Very minor problem | 16 | 10.7% | 34 | 23.0% |
| | 2 = Minor problem | 13 | 8.7% | 32 | 21.6% |
| | 3 = Moderate problem | 53 | 35.3% | 38 | 25.7% |
| | 4 = Serious problem | 26 | 17.3% | 15 | 10.1% |
| | 5 = Extremely serious problem | 21 | 14.0% | 7 | 4.7% |
| Can't see the benefits of technology | 0 = Not at all | 19 | 12.7% | 7 | 4.7% |
| | 1 = Very minor problem | 13 | 8.7% | 17 | 11.5% |
| | 2 = Minor problem | 12 | 8.0% | 14 | 9.5% |
| | 3 = Moderate problem | 35 | 23.3% | 40 | 27.0% |
| | 4 = Serious problem | 43 | 28.7% | 26 | 17.6% |
| | 5 = Extremely serious problem | 28 | 18.7% | 44 | 29.7% |
| Other | 0 = Not at all | - | | - | |
| | 1 = Very minor problem | - | | - | |
| | 2 = Minor problem | - | | - | |
| | 3 = Moderate problem | - | | - | |
| | 4 = Serious problem | - | | - | |
| | 5 = Extremely serious problem | 6 | 100.0% | 2 | 100.0% |

Source: Own compilation from the surveyed data

## 5. Discussion

### *5.1. The need for digital transformation*

Six groups of actors are involved in the Vietnamese mango value chain, each with distinct information needs, as detailed in Table 4.

Typically, value chain actors engage in three types of exchanges, but the exchange of information is considered the most critical (Fig. 2). In this chain, the consumer acts as the leader, and their expected value or requirements should be communicated effectively and seamlessly across the value chain. All stakeholders have emphasised the importance of enhancing the information flows within the mango value chain, and the application of DIT has been recognised as a promising solution. However, improving the adoption of DIT will require tailored solutions to address the specific barriers faced by value chain actors. These proposed solutions are summarised in Table 7.

Even though digital transformation is promised as a possible pathway to improve the efficiency of the value chain, our literature review identified that small farmers in developing countries face many challenges in the digital transformation process [19-22]. In our research areas, most farmers have a positive attitude towards digital technology, with 52.01% saying they will start using it. The remaining farmers suggest, "Not sure if I have money to invest in production technology," or "It's too difficult to use production technologies." It is also worth noting that the percentage of households planning to adopt new equipment and technology for production soon is low, averaging 36.91%. This rate in Dong Thap is 48% higher than in Son La (only 1.35%), suggesting that farmers in Dong Thap are more willing to apply technology and machines than farmers in Son La.

Interestingly, female farmers desire and plan to apply technology more than male farmers. The frequent barriers they pointed out include a lack of capital to invest in technology, no need to apply automation due to small-scale production, lack of digital skills and competencies, not knowing how to optimise technology use, and fear of change because of their age. Concerns about privacy/security, data security, and lack of availability or quality of internet connections are not serious barriers for mango farmers.

### *5.2. Possible focus domains of digital transformation to improve the efficiency of the mango value chain*

Adopting DIT could be a game-changer for Vietnam's agribusiness in general and for the mango export value chain in particular [49]. Digital devices could help actors communicate with others more easily, timely, and effectively than traditional methods such as face-to-face communication [50]. In addition, several studies have indicated that using digital technologies could lead to an increase in awareness and adoption of suitable agricultural technologies in production practices which

**Table 7. Main solutions to improve the digital information technology adoption to local farmers (n=298).**

| Adoption solution | | Dong Thap | | Son La | |
|---|---|---|---|---|---|
| | | *Count* | *%* | *Count* | *%* |
| 1. Increase connection and improve internet quality | 0 = Not necessary | 14 | 9.3% | 27 | 18.2% |
| | 1 = Very little necessary | 15 | 10.0% | 28 | 18.9% |
| | 2 = A little necessary | 8 | 5.3% | 9 | 6.1% |
| | 3 = Necessary | 16 | 10.7% | 41 | 27.7% |
| | 4 = Very necessary | 49 | 32.7% | 29 | 19.6% |
| | 5 = Extremely necessary | 48 | 32.0% | 14 | 9.5% |
| 2. Instructions on how to purchase and maintain the service | 0 = Not necessary | 9 | 6.0% | 12 | 8.1% |
| | 1 = Very little necessary | 14 | 9.3% | 26 | 17.6% |
| | 2 = A little necessary | 5 | 3.3% | 9 | 6.1% |
| | 3 = Necessary | 35 | 23.3% | 35 | 23.6% |
| | 4 = Very necessary | 42 | 28.0% | 38 | 25.7% |
| | 5 = Extremely necessary | 45 | 30.0% | 28 | 18.9% |
| 3. Increase number of trainings in technology use for employees | 0 = Not necessary | 9 | 6.0% | 5 | 3.4% |
| | 1 = Very little necessary | 15 | 10.0% | 12 | 8.1% |
| | 2 = A little necessary | 2 | 1.3% | 5 | 3.4% |
| | 3 = Necessary | 17 | 11.3% | 29 | 19.6% |
| | 4 = Very necessary | 39 | 26.0% | 31 | 20.9% |
| | 5 = Extremely necessary | 68 | 45.3% | 66 | 44.6% |
| 4. Increase number of trainings of farm management skills for workers | 0 = Not necessary | 6 | 4.0% | 5 | 3.4% |
| | 1 = Very little necessary | 11 | 7.3% | 20 | 13.5% |
| | 2 = A little necessary | 4 | 2.7% | 2 | 1.4% |
| | 3 = Necessary | 24 | 16.0% | 26 | 17.6% |
| | 4 = Very necessary | 33 | 22.0% | 41 | 27.7% |
| | 5 = Extremely necessary | 72 | 48.0% | 54 | 36.5% |
| 5. Increase number of trainings in counter-sales skills for employees | 0 = Not necessary | 8 | 5.3% | 3 | 2.0% |
| | 1 = Very little necessary | 15 | 10.0% | 22 | 14.9% |
| | 2 = A little necessary | 5 | 3.3% | 5 | 3.4% |
| | 3 = Necessary | 15 | 10.0% | 19 | 12.8% |
| | 4 = Very necessary | 38 | 25.3% | 39 | 26.4% |
| | 5 = Extremely necessary | 69 | 46.0% | 60 | 40.5% |
| 6. Dissemination of training on privacy, security and data safety | 0 = Not necessary | 12 | 8.0% | 20 | 13.5% |
| | 1 = Very little necessary | 16 | 10.7% | 27 | 18.2% |
| | 2 = A little necessary | 8 | 5.3% | 7 | 4.7% |
| | 3 = Necessary | 24 | 16.0% | 27 | 18.2% |
| | 4 = Very necessary | 29 | 19.3% | 30 | 20.3% |
| | 5 = Extremely necessary | 61 | 40.7% | 37 | 25.0% |
| 7. Demonstration model of the benefits of technology | 0 = Not necessary | 9 | 6.0% | 5 | 3.4% |
| | 1 = Very little necessary | 13 | 8.7% | 7 | 4.7% |
| | 2 = A little necessary | 4 | 2.7% | 5 | 3.4% |
| | 3 = Necessary | 18 | 12.0% | 23 | 15.5% |
| | 4 = Very necessary | 28 | 18.7% | 41 | 27.7% |
| | 5 = Extremely necessary | 78 | 52.0% | 67 | 45.3% |
| Other | 0 = Not necessary | - | | - | |
| | 1 = Very little necessary | - | | - | |
| | 2 = A little necessary | - | | - | |
| | 3 = Necessary | - | | - | |
| | 4 = Very necessary | 1 | 100.0% | 1 | 50.0% |
| | 5 = Extremely necessary | - | | 1 | 50.0% |

Source: Own compilation from the surveyed data.

resulting in reductions in production costs and higher efficiency [51-54]. Other research suggests that digital farm management technologies such as e-Diaries could ensure transparency, traceability, and food safety, while improving the quality of Vietnamese mangoes to meet the requirements of high-end customers [12-14].

The traceability system is a transparent mechanism to promote sustainable agriculture practices and create operational efficiency in the entire chain management [55-57]. This also creates a social impact for various stakeholders through sharing recorded and formulated information on mango production, grading, or processing. Moreover, the traceability feature is the added value for high-demand and cautious customers. End-user customers may access the relevant information for checking food safety and originality, including free pesticide test certificates, growing location, and growing methods [58].

All of these focus domains for DIT and potential impacts in the mango value chain are depicted in Fig. 3.

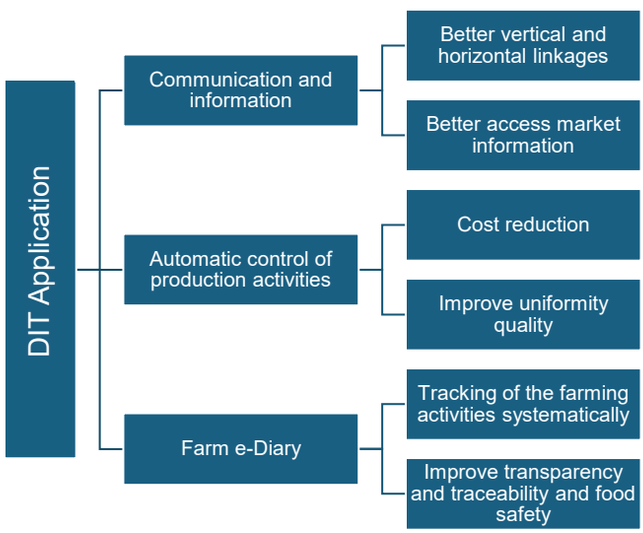


**Fig. 3. Focus domains for digital transformation and potential impacts in the mango value chain.** Source: Own compilation.

### *5.3. A pathway to digitising Vietnamese mango value chains*

Digital transformation is now a prevailing trend in modern food production supply chains. To improve the mango value chain's performance, stakeholders must recognise this trend and commit to the transformation process, supported by government interventions.

The Theory of Change analysis summarised the quantitative and qualitative data collected during this project into a flow or "pathway" diagram for ease of interpretation (Fig. 4). The roles of MARD and provincial DARDs are critical in facilitating DIT adoption, particularly through institutional approaches and available resources, including financial support.

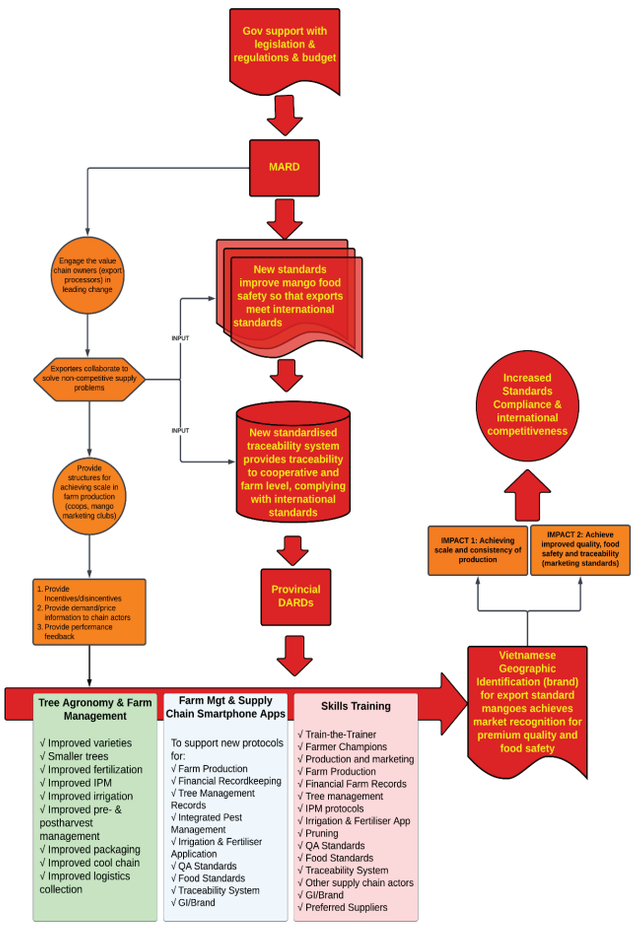


**Fig. 4. Pathway to digital information technology adoption in the Vietnamese mango export industry.** Source: Own compilation.

*First*, digital transformation should begin with improving information and communication flows, as previously discussed. A simple system to record, store, and share information should be developed to coordinate all value chain actors using low-cost digital technologies. This system must be designed to be both user-friendly and cost-effective. For instance, dominant value chain actors, such as large mango marketers or major food retailers, could consider investing in the development of a free, simple, smartphone-based app accessible to all value chain participants.

*Second*, extension training and capacity development programmes for farmers and other actors in the value chain should be prioritised. These programmes should focus on empowering female and younger farmers as beneficiaries and on developing basic digital skills, such as using smartphones for digital farm diary management and e-communication.

*Third*, the government should explore supporting the development and adoption of a digital system for tracing product originality and ensuring food safety compliance. This could involve the use of QR codes, barcodes, or item numbers. Additional details are presented in the three lower boxes of Fig. 4: tree agronomy and farm management, farm management and supply chain smartphone apps, and skills training.

## 6. Conclusions

Vietnam's mango value chain has significant potential to expand exports to high-income countries, but stringent customer requirements prioritise quality, food safety, and traceability. At present, the effectiveness of product, information, and governance flows within the value chain is suboptimal, particularly concerning information transfer.

To address these challenges, adopting DIT is essential for enhancing these flows. Effective dissemination of information from end consumers to farmers will facilitate better communication and improve overall efficiency. DIT has the potential to transform the value chain by enabling systematic information recording and sharing via digital platforms, thereby increasing transparency and consumer value through advanced traceability systems.

Although some digital technology applications are already in place, adoption levels remain low due to farmers' limited access to capital, inadequate technological skills, and lack of awareness of the benefits of DIT. To promote effective digital transformation, it is crucial to develop a user-friendly and cost-effective data management system, implement targeted training programmes, and introduce supportive policies mandating the use of digital technology for product traceability.

Successful coordination among value chain actors is vital for improving traceability, upholding quality standards, and ensuring food safety. This study identifies key focus areas for digital transformation and outlines a pathway for DIT adoption in the Vietnamese mango export industry, with an emphasis on governmental support and collaborative efforts among stakeholders.

## CRediT author statement

Nguyen Thi Thu Quynh: Develop ideas, outline, and write the article; Duong Nam Ha: Review the literature, Collect and analyse data, and Revise the article; Vu Ngoc Tan: Review the literature, Collect and analyse data, and Revise the article; Laurie Bonney: Develop the framework, Review the literature, and Revise the article; Morgan Miles: Develop the framework, Review the literature, and Revise the article.

## ACKNOWLEDGEMENTS

We would like to thank the Australian Centre for International Agricultural Research, the John Dillon Fellowship Program, and UNE for funding this study. Special thanks to the local governments, Dong Giao Foodstuff Export Joint Stock Company, mango cooperatives, and farmers in the provinces of Son La and Dong Thap for their great cooperation in the

implementation of this study as well as the joint effort of the Vietnam National University of Agriculture and Health and Agricultural Policy Research Institute project team in data collection.

## COMPETING INTERESTS

The authors declare that there is no conflict of interest regarding the publication of this article.

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