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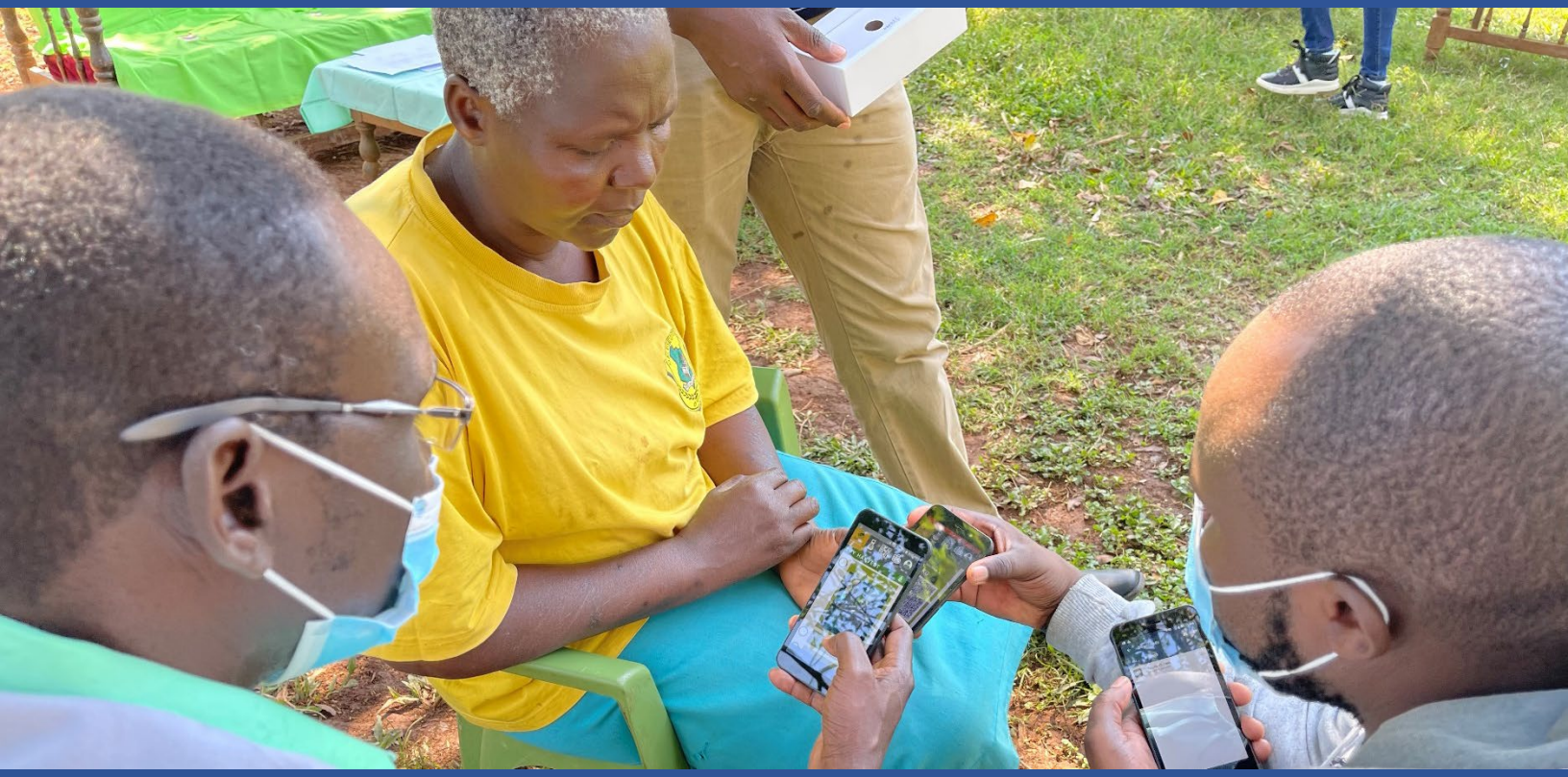

The Impact of Blockchain Technology on Food Insecurity through African Indigenous Vegetables in Western Kenya

Final Report

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About the Project

Exploring the Use of Blockchain Technology to Improve Food Security Through African Indigenous Vegetables in Western Kenya is one of the first projects undertaken to investigate how blockchain technology (BCT) can be deployed in horticultural value chains with the express purpose of improving food and nutrition security among all value chain actors. The project also focuses on understanding how digital platforms using BCT will secure the place of women and youth in the value chain. This report documents the impacts of this twelve-month project. Additional information can be found on the project website. This project was made possible through a LASER PULSE grant, funded by USAID.

Project Partners

Virginia Polytechnic Institute and State University – Research Lead

Egerton University – Research Partner

AgUnity – Research Translation Partner

About LASER PULSE

LASER (Long-term Assistance and SErvices for Research) PULSE (Partners for University-Led Solutions Engine) is a five-year, $70M program funded through USAID's Innovation, Technology, and Research Hub, that delivers research-driven solutions to field-sourced development challenges in USAID interest countries. A consortium led by Purdue University, with core partners Catholic Relief Services, Indiana University, Makerere University, and the University of Notre Dame, implements the LASER PULSE program through a growing network of 2,500+ researchers and development practitioners in 61 countries.

About this Publication

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Abbreviations

AIV	African Indigenous Vegetables
BCT	Blockchain Technology
CBO	Community-based Organization
DAT	Digital Agricultural Technologies
DDS	Diet Diversity Score
FAO	Food and Agriculture Organization
FIES	Food Insecurity Experience Scale
GOK	Government of Kenya
ICT	Information Communication Technology
KES	Kenyan Shilling
LASER PULSE	Long-term Assistance and Services for Research (LASER) Partners for University-Led Solutions Engine (PULSE)
LMIC	Low- and Middle-Income Country
MoALF	Ministry of Agriculture, Livestock, and Fisheries
PVCA	Participatory Value Chain Analysis
SSA	Sub-Saharan Africa
VC	Value Chain

Executive Summary

This study is one of the first to explore how blockchain technology (BCT) could be used to improve food security in communities that are reliant on agriculture but are the last to receive services or access to markets, known as the 'last-mile'. The goal was to determine how BCT could contribute to improving the income of African indigenous vegetable (AIV) value chain actors (e.g., producers, traders, and retailers) and to the affordability, availability, and accessibility of nutritious foods like AIVs for consumers. It finds that BCT can simultaneously strengthen the functionality of an *entire* agri-food value chain by increasing the efficiency of transactions among value chain actors, improving cooperation along the value chain, and enhancing access to information. A decrease in post-harvest loss, reduction in negotiation and search costs, and traceability of Grade A vegetables were facilitated by the blockchain functionality of the AgUnity V3 SuperApp. Producer income was improved by better meeting market demand, time savings on AIV activities, increasing the supply of Grade A vegetables, and making information on the vegetables more available to consumers. Increased incomes led to improved food security among producers by facilitating their ability to procure more food, especially higher quality proteins and fruits. Participants and consumers reported an increase in the consumption of AIVs over the study period because of increased quality, availability, and awareness of their nutritional importance.

AIV production in Kenya and other East African countries declined several decades ago due to increased pressure on small-scale producers to grow cash crops such as maize and sugarcane and the popularity of 'exotic' vegetables (i.e., cabbages, spinach, tomatoes, and onions). Fortunately, in the last decade, there has been a resurgence in focus on AIVs among researchers, nutrition practitioners, and consumers given their cultural and nutritional significance and economic potential. AIVs' superior nutritional profile also makes them ideal candidates for addressing malnutrition in Kenya.

Key Takeaways

1 – Blockchain technology can improve **trust and transparency** within agricultural value chains.

2 – Food security can be positively impacted through value chain strengthening by **improving incomes, reducing waste,** and **increasing the availability and desirability** of nutritious foods like African indigenous vegetables.

3 – The BCT app significantly **reduced the time producers spent trying to coordinate the sale of AIVs,** which led to the diversification of income sources for producers, especially women.

4 – **Corruption and exploitation** by dishonest brokers can be significantly reduced by creating a network of trusted actors and providing access to reliable market information.

AIVs' contribution to food and nutrition security will only be realized when their value chain functionality is improved. According to an initial value chain analysis and previous research, the main value chain inefficiencies that constrain the contributions that AIVs make to food and nutrition security are an insufficient flow of information through the value chain,

mismatched markets, poor vertical coordination between actors, and a lack of trust and transparency.

This study investigates how BCT can be deployed in AIV value chains with the express purpose of improving food and nutrition security among all AIV value chain actors, including consumers. The study also focuses on understanding how digital platforms using BCT will secure the place of women and youth in the agricultural value chain as upgrading activities usually attract men to participate.

Hypotheses

HYPOTHESIS 1 – The blockchain application improves functionality of the value chain by improving transaction efficiency and the flow of information between actors.

HYPOTHESIS 2 – Improved functionality of the value chain will increase incomes of value chain actors, especially women and youth.

HYPOTHESIS 3 - Increased incomes of VC actors lead to improved food security at the household level.

HYPOTHESIS 4 - In retail outlets, the blockchain application will improve the marketability of AIV varieties by addressing gendered factors that influence food purchase, preparation, and consumption.

HYPOTHESIS 5 - Increased marketability will translate into increased purchases by low-income households for AIVs.

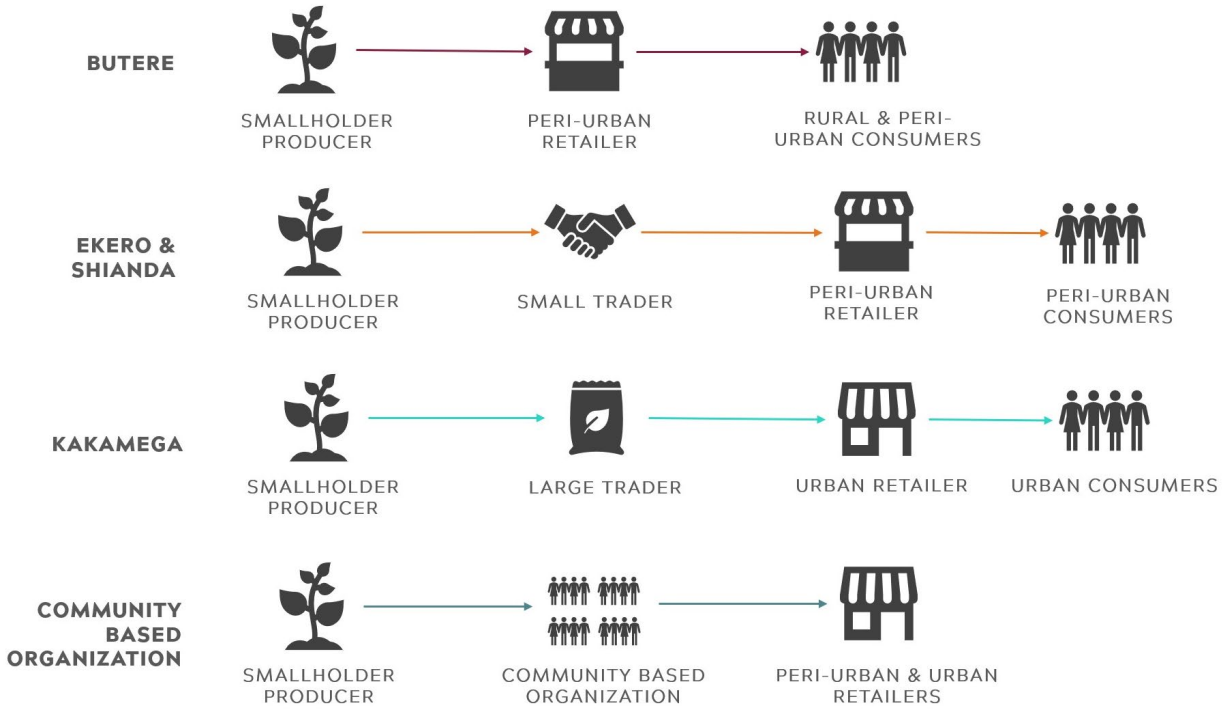
HYPOTHESIS 6 - Value chain actors will be willing to pay a small fee for the blockchain application for the economic and nutritional benefits derived from its use.

The study was undertaken through a collaboration between Virginia Tech, Egerton University, and the tech start-up AgUnity. An embedded research translation model was used to adapt AgUnity's blockchain-based smartphone application (app) to the AIV value chain in Kakamega county. A non-experimental longitudinal study design was used to conduct an impact evaluation based on six core hypotheses.

The AgUnity BCT-based V3 SuperApp was selected as the test case for this study since it uses the distributed ledger functionality of blockchain to establish a secure record-keeping system for all transactions that occur along the value chain. Each time a buyer and seller agree on the cash price for a certain amount of a vegetable, they both capture and approve this transaction in their app, which creates a block of information that is added to the blockchain. This information stored on the blockchain is immutable, giving users confidence that their records of transactions are accurate and reliable. It is also able to create traceability of information along the value chain, communicating characteristics of the vegetables from the producer through to the consumer.

Over six months, 56 smartphones containing the AgUnity BCT-based app were distributed to selected producers, traders, and retailers to explore how the platform could improve food security and address the challenges faced by last-mile agricultural communities. The study participants were selected using purposive and snowball sampling methods to ensure actors across each node of four different value chain configurations were included (depicted below). Each participant was provided with a free smartphone as a way of compensating them for time spent in trainings, working with the research team to co-design the app, and for participating in baseline, midline, and endline evaluations. A subset of participants also engaged in focus group discussions during the endline

evaluation in each study location. Finally, baseline, midline, and endline questionnaires were also conducted with consumers in the markets where participating retailers sold AIVs.



Blockchain technology has the potential to transform the *entire* AIV value chain.

The blockchain functionality of the AgUnity app was found to improve the functionality of the *entire* value chain over the six-month period of evaluation (Hypothesis 1). An important factor behind the improved value chain functionality was the strong connectivity between producers and traders, which significantly reduced the time spent trying to coordinate the sale of AIVs. Since transactions in the AgUnity BCT-based app can only occur between actors registered in the network, coordination and cooperation were easier since each user had access to a known group of individuals they can transact with. Some 92% of producers and 87% of traders and retailers reported that using the AgUnity app improved their relationships with the people they transact with. There was also a strong preference for transacting with those in the AgUnity network versus those who were not, especially among traders. AIV producers used their time savings to engage in additional productive or social activities.

The transaction data captured by the AgUnity app also provided producers with invaluable information on the revenues obtained from different vegetables. Prior to participating in this project, only 30% of participants kept paper-based records and none used mobile technology for record-keeping. These records assisted value chain actors in better matching supply to demand and reduced the difficulty for retailers in finding demanded AIV varieties. **Overall, transaction costs in the AIV value chain were significantly reduced by the BCT-based AgUnity V3 SuperApp.**

Improvements in value chain functionality due to the BCT app led to an improvement of producer incomes, especially for women, from on-farm activities (Hypothesis 2); however, traders' income decreased across all sources of income, while retailers' income increased from on-farm activities and employment. **The increased value chain functionality allowed producers to diversify their income, increasing their off-farm and employment-based income over the 6-month study period.**

There was clear evidence that food security did increase over the 6-month study period (Hypothesis 3). Households demonstrated an ability to purchase higher quality proteins and fruits when compared to the baseline. In addition to increased income, the focus of the project on the nutritional quality of AIVs and how to use these characteristics to market products to consumers also helped to increase the demand of participants for the leafy greens.

Vegetable quality and information about how the vegetables were produced were found to be important factors shaping purchasing decisions (Hypothesis 4). BCT created an incentive for producers to increase the marketability of AIVs. By the endline study, 100% of traders and the majority of producers were using a formal grading process introduced as part of this study to trace Grade A vegetables from farm to point of sale. **Consumers perceived a significant increase in the quality and availability of AIVs from the baseline to endline**, but still had limited access to information on the inputs used in the production of AIVs, production practices, water quality, and how the vegetables were transported.

Over the 6-month study, retailers reported an improvement in the marketability of AIVs, including a willingness among consumers to pay a price premium – estimated to be as much as a 10 to 30 KES – for Grade A vegetables (Hypothesis 5). There was also a self-reported increase in the volume of vegetables study participants purchased. For all participants, better quality was the leading factor driving the increase, followed by better prices and more awareness of the nutritional importance of AIVs. **All value chain actors, including consumers, self-reported an increase in consumption of AIVs, due to increased quality, availability, and awareness of the nutritional value.**

Since the study participants were provided a smartphone and were not asked to pay a subscription fee to use the AgUnity app, the study explored potential pricing models for the BCT service. Finally, approximately 75% of producers, traders, and retailers indicated they were willing to pay 150 KES per month to continue to use the AgUnity app (Hypothesis 6); however, to be willing to pay this price, the app would also need to offer complementary services and features. **In addition to participants' willingness to pay, members of their communities were also willing to pay both $75 and the monthly service fee of 150 KES in order to join the AgUnity network.**

Recommendations and Implications

This impact evaluation identifies the potential value that BCT can offer last-mile agricultural systems to improve value chain functionality and livelihoods. BCT cannot offer solutions for all the challenges faced by AIV value chain actors; however, there are clear linkages between the technology and food

security outcomes. The following recommendations outline several areas where technology companies (i.e., AgUnity) and enthusiasts, policymakers, and practitioners can facilitate the research and development needed to fully capture the transformative potential of BCT.

Recommendation 1. Developing low-tech traceability solutions should be a core priority for increasing demand for nutritious foods and creating economic returns for the producers of those foods.

The demand for high-quality, organic AIVs is growing in Kenya. By integrating traceability into AIV value chains, producers using traceability solutions will earn a first-mover advantage by meeting unmet consumer desires for information. This will lead to improvements in income, food security, and livelihood resilience.

Recommendation 2. Developing assistive technologies and monitoring mechanisms that minimize human interference will allow the full potential of BCT to be realized in agri-food systems.

There is a need to develop monitoring mechanisms to provide consumers with external assurance of the quality of vegetables and if they were produced organically. There is also a need to develop assistive technologies, such as internet of things sensors or weigh scales, that will minimize human interference in the metadata of the vegetables. If these solutions can be identified, national stakeholders would be able to leverage BCT to scale up compliance to standards across sectors. This in turn would develop consumer confidence in locally-produced horticulture products and facilitate access to export markets.

Recommendation 3. CBOs and other producer associations should be engaged to achieve network scalability and acceleration of transaction cost reduction.

The CBO *New Vision* was imperative to the success of this project. CBOs are adept at community transformation, encouraging behavior change, and harmonizing the community response. Working with CBOs, cooperatives, and farmer/agribusiness associations going forward will help to achieve scale in blockchain-based transacting networks. This will also lead to accelerated reductions in transaction costs in the agri-food system, leading to both increased income and a lower cost of food, both of which will contribute to improved national food security.

Recommendation 4. BCT should be deployed alongside complementary digital services.

The initial value chain analysis and outcomes observed in the impact evaluation reveal that BCT alone cannot address the pain points constraining the functionality of AIV value chains. Producers, traders, and retailers need access to advisory and extension services, financial services, weather information, and markets for their produce that will continue to minimize transaction costs and ensure they are fairly compensated for their respective activities in the value chain. One of the main findings of this

project is that it is not BCT, but *BCT Plus Services* that has the most potential to alleviate the pain points of last-mile agricultural systems.

Recommendation 5. Digital solutions should not be a replacement for in-person technical training and capacity building.

Digital solutions are not a substitute for in-person interaction and engagement to build technical skills in producing or retailing agricultural products will continue to be invaluable. While some of the training that is needed to address production and retailing challenges of AIVs could be offered digitally, in-person engagement to problem solve and examine the existing practices used will be essential for improving productivity sustainably.

Introduction

In sub-Saharan Africa (SSA), 70% of livelihoods depend on agriculture, especially smallholder crop production, animal husbandry, and other small agri-businesses. These agricultural workers, roughly half of whom are women, produce 60 to 80% of food in the continent. According to Mellor (2017), a 1% increase in agricultural GDP results in a 2.6% reduction in poverty, compared to a 0.25% reduction in poverty with a 1% increase in overall GDP. The impact of smallholder productivity on poverty in particular places agriculture as a key priority for improving livelihoods, resilience, and food and nutrition security (Arndt et al. 2010).

Kenya has demonstrated leadership in the SSA context for driving agriculture sector growth and improving food security through policy frameworks (i.e., including food security in the country's 'big four' priorities), demonstrating openness to innovation, and creating favorable investment environments. However, one-third of the population remains under the international poverty line, 2.1 million are facing acute food insecurity (up from 1.3 million in 2020), and women and other socially excluded populations (i.e., the elderly, persons with disabilities) have been disproportionately excluded from accessing the increased wealth in the country (USAID 2020; IPC 2021; WFP). Furthermore, the COVID-19 pandemic has exacerbated poverty, food insecurity, and malnutrition. Continued innovation is required to advance agriculture sector transformation to achieve 100% food and nutrition security in the country (FAO et al. 2020; GoK 2017).

With deepening access to mobile phones, the internet, and other information and communication technologies (ICTs) in SSA over the last two decades, the private sector, technologists, agriculturalists, development agencies, government, and researchers, have turned towards digital agricultural technologies (DATs) as potential remedies for the multitude of challenges afflicting the food and fiber farming sectors. There is a growing consensus that DATs can contribute to widespread agricultural sector transformation, productivity growth, and improved access to services, factors, and output markets (De Ruyter de Wildt et al. 2019).

Blockchain technology (BCT) has emerged as a prominent DAT that offers compelling value chain development solutions for difficult challenges such as high transaction costs, the opacity of value chains, lack of trust between transacting parties, and lack of consumer confidence in final products (FAO and Zhejiang University 2021). BCTs' distributed immutable ledger functionality has the potential to more accurately value food, address market failures, capture and secure data along the chain, create an ecosystem for data-sharing, reduce value chain corruption, and improve trust, traceability, transparency, and efficiency (De Ruyter de Wildt et al. 2019; Tripoli and Schmidhuber 2020). While the number of private sector companies that offer BCT-based traceability in food supply chains is increasing, particularly in a high-income country context, there is little evidence to substantiate the benefits that BCT can generate for last-mile farmers[1] in a low- and middle-income country context. There are also no studies that investigate if BCT can create returns to food and

[1] Last-mile farmers are farmers who typically are last to receive services or access to markets.

nutrition security by improving the functionality of value chains for nutritious foods and improving value chain actor income.

According to a World Bank report on DATs in Africa, Kenya is ranked as the leading regional innovation hub with the largest number of scalable DATs, followed by South Africa and Nigeria. As internet and mobile phone access grows, users move along a continuum of technology adoption (Figure 1) (Kim et al. 2020). In the low internet penetration and low mobile access environments, SMS-based applications and mobile payment services dominate. However, as internet connectivity and mobile phone access reaches a critical mass, advanced big data analytics and farm robotics applications have increased in usage. Thus, Kenya is at an appropriate stage of the digital technology adoption continuum to test the potential for an advanced DAT like blockchain.

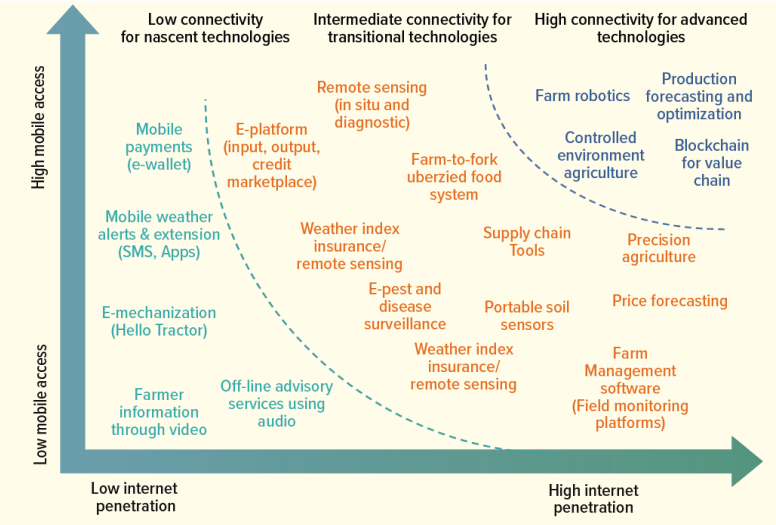


Figure 1. Digital technology adoption continuum
Source: Kim et al. 2020

Virginia Tech (USA) and Egerton University (Kenya) partnered with the Australian tech start-up, AgUnity, to conduct the study *Exploring the Use of Blockchain Technology to Improve Food Security Through African Indigenous Vegetables (AIVs) in Western Kenya*. AIVs were selected as the focus of this study because they are an important food security crop in Kenya given their short growing season, ownership of production and marketing by women, and their nutritional value. However, the full economic and nutrition potential of AIVs has not yet been realized due to value chain inefficiencies and constraints. The research started with a formative phase that included an in-depth gender-sensitive value chain analysis of AIVs to inform adaptations of AgUnity's blockchain-based application to the Western Kenyan AIV context (Agnew et al. 2021). The second phase consisted of introducing AgUnity's blockchain-based application into the AIV value chain to assess if food security can be improved by increasing incomes and the availability and desirability of AIVs by improving the functionality of the AIV value chain.

The findings of this study will assist policymakers, development practitioners, agricultural sector stakeholders, and technology enthusiasts and companies alike to understand the complexities of introducing an emerging technology like BCT into last-mile agricultural value chains, the impacts and unintended consequences of introducing the technology, and the extent of evidence still needed to leverage digital solutions to transform agriculture in Kenya and other SSA countries.

Theory of Change

The evidence of blockchain technology's (BCT) contribution to strengthening agri-food value chains has been steadily mounting since 2020 (Liu et al. 2021). Information sharing, data integrity, value chain efficiency, traceability, improved trust between actors, and data-driven decision-making have been a few of the investigated impacts to date. However, research has yet to investigate if BCT can be leveraged to improve food security and nutritional outcomes by improving the functionality of agri-food value chains that produce nutritious foods.

AIVs were selected as the focus crop for this study since they support food security by generating income and providing important micronutrients to the diet. However, the preliminary AIV value chain analysis conducted for this study and other research in western Kenya demonstrates that the food security benefits of the leafy greens have not yet been fully captured due to value chain inefficiencies. While demand for AIVs is growing in Kenya, there is an insufficient flow of information through the value chain, markets are mismatched, there is poor vertical coordination between actors, and value chain actors' relationships are characterized by a lack of trust and transparency (Gido, Ayuya, Owuor, and Bokelmann, 2016; Kansiime et al. 2018). This results in inconsistent supply and quality of AIVs in markets throughout Kenya. The characteristics of BCT are well suited to address these value chain inefficiencies (see Agnew et al. 2021). Figure 2 outlines the types of market arrangements that exist in AIV value chains in Western Kenya.

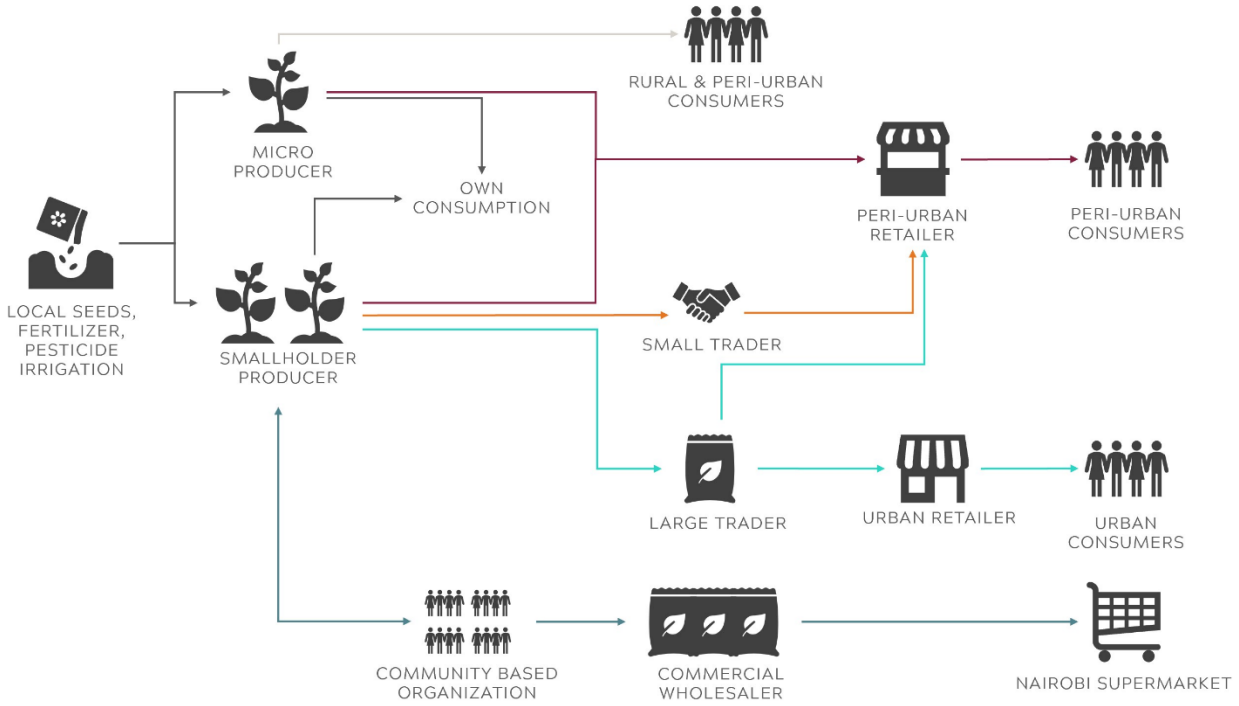


Figure 2. AIV value chain in Kakamega County

DATs like BCT can contribute to improvements in food security both by increasing income, allowing households to purchase more expensive but often nutrient-rich foods (e.g., animal source foods), and by increasing the availability and desirability of nutritious foods, through strengthening inefficient value chains of nutritious foods. However, this requires that digitization addresses the key pain points that value chain actors face in carrying out their respective activities and transactions and that they are able to sustain use of the technology and services over the long term. For value chain actors to use BCT in their transactions and continue to do so over the long-term, there are four key antecedents:

1 - Value chain actors (i.e., producer, trader, retailer) who transact with one another are willing to participate in the system that is intended to be more open and transparent.
2 - Value chain actors can own and retain a smartphone powerful enough to host a blockchain-based application.
3 - Value chain actors can use the smartphone and are able to understand how to execute the double handshake scanning process.
4 - Users have access to technical support and training.

Underpinned by these assumptions and based on existing evidence that demonstrates BCT's ability to strengthen value chain inefficiencies, this study investigated the following theory of change and hypotheses.

IF *the AgUnity blockchain-based smartphone application can improve the functionality of the AIV value chain in western Kenya, and* **IF** *improved functionality contributes to an improvement in the income of value chain actors* **AND** *an increase in the availability and desirability of AIVs in local markets,* **THEN** *food security will be improved among value chain actors, including end consumers.*

Hypothesis 1 - The blockchain application improves the functionality of the value chain by improving the efficiency of transactions and the flow of information between actors.

Value chain functionality is the state where transaction costs (i.e., financial, labor, search and information, and bargaining costs) are minimized, value chain actors (i.e., producer, trader, and retailer) cooperate to deliver affordable, safe, and high-quality products to the final market, value chain actors are fairly compensated for their respective activities, and supply meets demand.

It was expected that the AgUnity BCT-based smartphone application would reduce transaction costs by improving transaction efficiency, which is defined as the minimization of time, effort, and money involved in the completion of a transaction between two parties (Transaction Commons 2019). Improved transaction efficiency was anticipated because BCT can improve the reliability, accuracy, and timeliness of transactions by locking in agreed-upon quantities and purchase prices, creating

verified and secured transaction records, improving coordination and cooperation between actors, and enhancing trust and transparency.

Improved flow of information through the AIV value chain would allow value chain actors to cooperate to deliver affordable, safe, and high-quality AIVs to the market and for each actor to be fairly compensated for their respective activities (Agnew et al. 2021). Increased transparency regarding the vegetables was expected to incentivize improved production and quality. Creating a more cooperative value chain and improving access to information about the consumers' demands was expected to enable producers to consistently meet demand in terms of quantity, variety, and quality of the AIVs. Providing access to transaction history was expected to increase the negotiating power of producers and reduce the opportunistic behavior of buyers (both traders and retailers).

Hypothesis 2 - Improved functionality of the value chain will increase the incomes of value chain actors, especially women and youth.

According to the initial value chain analysis, income from AIVs, especially for producers, was constrained due to the limited functionality of the value chain. A consistent mismatch with supply and demand, lack of insight into characteristics demanded by the consumer, lack of reliable transactions, and post-harvest loss due to lack of buyers, were contributors to not fully realizing the economic potential of growing and selling AIVs. By reducing transaction costs and improving the flow of information, it was expected AIV supply would better match demand (which is ample throughout the country), and the incomes of producers (the majority of whom are women) would increase.

Hypothesis 3 - Increased incomes of value chain actors and increased availability and desirability of AIVs, lead to improved food security among value chain actors.

An increase in income and an increase in the availability and desirability of nutritious foods are known drivers of increased food security (Henson and Humphrey, 2015). While the main outcome of interest was an increase in producer income, since they currently receive the lowest share of the final price paid by the consumer (Agnew et al. 2021), it was anticipated that strengthening the value chain functionality would lead to an increase in income for traders *and* retailers. Since all actors in the value chain have experienced food insecurity (Agnew et al. 2021), it is important to emphasize the role of improved value chain functionality in the livelihoods of everyone participating in the production and sale of AIVs.

Hypothesis 4 - In retail outlets, the blockchain application will improve the marketability of AIV varieties by addressing gendered factors that influence food purchase, preparation, and consumption.

Improved value chain functionality was expected to improve the marketability of AIVs to the end consumer by increasing the flow of information between value chain actors of the demanded AIV characteristics (i.e., grown without pesticides), varieties, and quantity. It was also expected to improve marketability by providing traceability of these characteristics. While eventually monitoring mechanisms and a consumer-facing application would be needed to fully capture the benefits of

traceability offered by BCT, it was expected that an initial introduction of the traceability concept would capture consumer attention in the market where value chains are almost completely opaque.

Hypothesis 5 - Increased marketability (i.e., affordability, types of varieties available, accessibility, knowledge of preparation of vegetables) will translate into increased purchases by low-income households for AIVs.

Increased desirability of nutritious foods is known to contribute to improved consumption (Henson and Humphrey, 2015). It was expected that improving the functionality of AIVs in Kakamega County would also contribute to improvements in food security in consumer households by increasing the consumption of the nutritious leafy greens.

Hypothesis 6 - Value chain actors will be willing to pay a small fee for the blockchain application for the economic and nutritional benefits derived from its use.

It was hypothesized that the records generated by AgUnity's blockchain-based smartphone application would generate enough value among users that they would be willing to pay a small subscription fee to continue using the app past the life of the project.

Study Design

This study used a non-experimental impact evaluation approach to investigate if blockchain technology could improve food security through higher incomes and increased consumption of vegetables by strengthening African indigenous vegetable (AIV) value chains in western Kenya.[2] This study also employed the LASER PULSE embedded research translation (ERT) model, which is "an iterative co-design process among academics, practitioners, and other stakeholders in which research is intentionally applied to a development challenge" (LASER PULSE).

In three sub-counties and one town in Kakamega County, 56 value chain actors (i.e., producers, traders, and retailers) participated in this study. Each received a phone that was powerful enough to host the AgUnity blockchain-based application, known as the V3 SuperApp. Participants first received their phone in May 2021 and the final evaluation of the project was conducted in November 2021. AgUnity staff assisted by faculty from Egerton University, verified participants' identities, conducted the onboarding process for the application,[3] trained them on the basics of smartphone usage, and trained them how to use the app. To use the blockchain functionality, a double handshake takes place between buyers and sellers by scanning a QR code.[4] AgUnity hired a local field officer who conducted repeated training on the scanning process.

Study Area

Kakamega County is located in western Kenya, near the border of Uganda (Figure 3). In 2019, the population was approximately 1.8 million (GoK 2019). As of 2016, the absolute poverty rate was approximately 36%, compared to the national average of 37%, and the rate of food poverty was approximately 33%, compared to the national average of 32% (GoK 2017). Kakamega is one of four counties that has the highest rate of multi-dimensional and monetary poverty in absolute numbers in the country (KNBS 2020).

Figure 3. Kakamega County
Source: https://kenya.opendataforafrica.org/

Kakamega County is one of the country's major AIV producers as horticultural production can take place most of the year (Laibuni, Losenge, and Bokelmann 2020). Most vegetable production is carried out by female small-scale producers (MoALF 2017). Accordingly, irrigation and horticultural production are core poverty

[2] The research protocol and all data collection instruments were approved by the Biomedical Research Alliance of New York (Protocol No. 20-059-568) and the Egerton University Research Ethics Committee (Approval No. EUREC/APP/113/2021).
[3] AgUnity. 2022. *Trainer Guide* (Bali, Indonesia).
[4] See this video for a demonstration of transactions on the AgUnity V3 SuperApp.

reduction strategies in the region (County Government of Kakamega, 2018). Other crops produced in Kakamega include maize, sugarcane, bean, cassava, finger millet, and sorghum (MoALF 2017).

This study was carried out in the sub-counties of Butere, Mumias, Ekero/Shianda, and the town Kakamega. These study locations were selected as they each produce and sell significant volumes of AIVs. They also represent different vertical coordination arrangements between producers, traders, and retailers. Four markets were selected in each of the study locations where participating retailers were located. These markets were selected because they primarily serve consumers in the third- and fourth-income quintiles. Since preparations for the elections were starting, there was sensitivity around collecting income data in public locations. Therefore, market selection was used to identify 'low-income' consumers rather than asking participants about their income.

Sampling Approach

The number of participants was determined by the project budget, which covered the cost of the smartphones. This approach was used as a way of compensating the participants for time spent in training, working with the research team to co-design the app, and for participating in baseline, midline, and endline evaluations.

Four types of value chain arrangements were found in the study areas (Figure 4), illustrating the informal and unstructured nature of AIV transactions. These sub-chains were used to guide the selection of participants, starting from retailers and tracing through the value chain to identify the producers and other actors that supply them. Purposive and snowball sampling methods were used to identify the participants for this study. A pre-recruitment checklist was conducted to ensure that they were qualified to participate (i.e., entering of their own free will, over the age of 18, and farmed or traded AIVs) and to meet our target participation rate of women, men, and youth (at least 50% men and women and at least 30% youth).

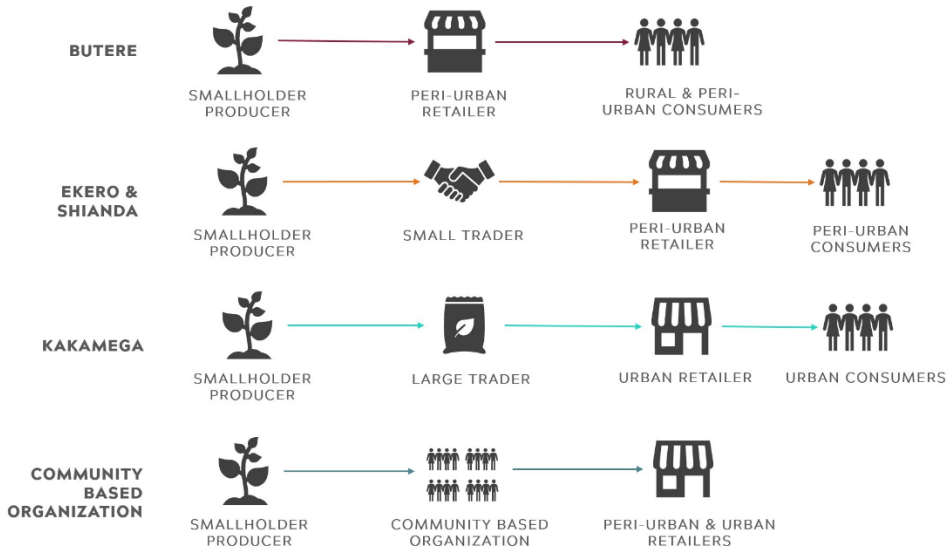


Figure 4. Study value chain arrangements

Embedded Research Translation Process

Research partners Virginia Tech and Egerton University selected the Australian tech startup, AgUnity, as the research translation partner. AgUnity's V3 SuperApp is an out-of-the-box smartphone application built on BCT that can be adapted to various last-mile agricultural contexts and value chains (Figure 5). Since its inception, AgUnity has focused primarily on working in value chains for cash crops that tend to be more formalized or straightforward (i.e., coffee, cocoa). The ERT model provided a valuable process for adapting the app to a more informal value chain.

Figure 5. AgUnity V3 SuperApp interface

The iterative ERT co-design process conducted with project participants led to the adaptation of AgUnity's BCT smartphone application to the context of AIV value chains. The app functionality and the business processes in which the app is used (i.e., transactions) were designed to address the pain points of AIV value chain actors including a lack of coordination in the value chain, a lack of assurance of vegetable safety, the poor transmission of information, a lack of standardized grading and pricing, the weak market power of women, and the need for technical assistance (Agnew et al. 2021). The app's user interface is designed for low literacy and lack of familiarity with using smartphone applications. It was also translated into Swahili for this project.

Over the life of the project, the ERT process involved repeated interaction with the project participants to create opportunities for them to provide feedback and present challenges or insights that could be reflected in the app. AgUnity hired a field officer to ensure that this continuous engagement was possible. Virginia Tech and Egerton University also conducted meetings with participants 3 months after deployment to obtain additional feedback. Details on the app's functionality and implementation can be found in the deployment report (Kristofikova, Muskoke, and Agnew, 2021).

Impact Evaluation

Value chain participants were followed longitudinally between the initial deployment of the phones (May 2021) and the end of the project period (November 2021). The impact evaluation included: (1) a baseline and endline structured questionnaire; and (2) voluntary participation in an endline focus group. A total of 4 focus groups were conducted – 1 in each of the sub-county locations. A baseline, midline, and endline questionnaire were also conducted with consumers in the markets where

participating retailers were located to identify changes in market availability of AIVs, consumer demand trends for AIVs, awareness of vegetables sold using blockchain, etc.

Baseline and Endline Questionnaire

Baseline and endline questionnaires were conducted by students from Egerton University.[5] The baseline questionnaire took approximately 1.5 hours to complete and preceded the AgUnity phone onboarding process. The endline survey took approximately 1 hour to complete. At both baseline and endline, surveys were collected at a common meeting point. Participants received compensation for their transportation costs to travel to the designated location. Responses were recorded on a tablet using the Qualtrics Offline App. Responses were checked daily for accuracy.

The questionnaires covered topic areas such as (anticipated) effects of technology adoption, activities related to AIV production or sale, activities related to the participant's respective role in the value chain, food security, gendered dimensions of value chain participation and household dynamics, financial literacy, and quarterly income-based on income-generating activity.

Some participants missed the original onboarding day. There were also challenges in getting enumerators and trainers back to the field because of COVID-19 restrictions. As such, there were 3 participants at both baseline and endline that were not surveyed. Three participants were not surveyed at the endline because they were out of town. Three producers withdrew from the study but were replaced by a family or community member of their choosing. Table 1 breaks down the number of participants surveyed at baseline and endline by female and male participants.

Table 1. Questionnaire respondents by value chain role and gender

	Female		Male	
	Baseline	Endline	Baseline	Endline
Producer	20	20	17	18
Retailer	10	7		
Trader	5	7	1	1

Focus Groups

Focus groups were jointly held by AgUnity's Program Director, Nurvitria Kristofikova, and Virginia Tech's co-PI, Jessica Agnew (Figure 6). The purpose of the focus groups was to understand the overall experience with the phones, the participants' perception of its continued use, ideas to build on and scale, and the challenges and benefits of using the phone in their respective value chain activities. The purpose of the focus groups was to hear the perspectives of the participants in their own words, rather than to elicit the impacts through the baseline and endline surveys alone. These focus groups later helped to further understand the observed changes (or lack thereof) between baseline and endline questionnaires.

[5] Questionnaires can be shared upon request.

Focus groups were recorded with the permission of the participants. Flip charts and stickers were also used to record participant responses and the guides used were designed for low literacy. Extensive notes were also taken by the facilitator. The focus groups were held in Swahili and translated by the AgUnity field officer.

Figure 6. Farmers, traders, and retailers participate in an endline focus group

Consumer Baseline, Midline, and Endline

Structured questionnaires were conducted at baseline, midline, and endline with consumers in five participating markets in each of the sub-counties of Butere, Shianda/Ekero, Mumias, and Kakamega. The questionnaires were conducted by Egerton students and took place in the markets. The baseline and endline survey took approximately 15 to 20 minutes to complete and included questions on consumer perceptions of AIVs, the varieties they purchase, their availability and quality, nutritional awareness, and concerns about the AIVs. A total of 50 and 62 consumers were surveyed in the baseline and endline, respectively.

The midline questionnaire took approximately 5 minutes to complete and did a deeper dive on consumer willingness to pay for various characteristics of AIVs, such as being grown organically. The midline survey was used to align activities between value chain actors and consumers, i.e., making Grade A vegetables more widely available and having information on the vegetables provided at the retail outlet. A total of 438 consumers were surveyed at the midline.

Data Analysis

Quantitative, descriptive data were analyzed using Tableau. The Exact McNemar test for paired binomial data was used to test the statistical difference in proportions pre-and post-intervention, meaning, that this change would likely be observed in another simple random sample. The exact p-value binomial test was used given the small sample size. A paired t-test was used to validate the significance of mean changes observed between baseline and endline. Table 2 describes the statistical methods of estimation for the indicators used in this report.

Table 2. Indicator Estimation

Indicator	Method of Estimation	Source
Food Insecurity Experience Scale (FIES)	There are three methods for estimating FIES in a population. First, a respondent's raw score aggregates the affirmative responses to the eight FIES questions. The raw score is ordinal, with higher scores representing more severe experiences of food insecurity. Second, given respondents' raw scores, the probability that a respondent experiences certain thresholds of food insecurity is calculated. Third, the prevalence of food insecurity in a population is estimated based on the weighted sum of the raw-score probabilities. This report uses the raw score to measure changes in participants' food insecurity experience. Publications for peer review will assess the FIES probability.	FAO FIES
Diet Diversity Score	Household diet diversity was calculated based on a 24-hr recall. The number of 12 food groups consumed in the recall period is aggregated to create the score. The HDDS is a proxy for the household's ability to access food and socio-economic status.	Swindale & Bilinsky, 2004

Qualitative data were analyzed by coding transcripts and notes conducted from the focus groups. Recording of codes and alignment with study hypotheses was conducted using Excel. The list of coded themes was expanded during analysis until themes reached saturation.

Qualitative and quantitative data were used to triangulate the findings in the impact evaluation and provide rich insight into the observed outcomes. Consumer data further enriched the findings in addition to understanding changes in their behavior.

IMPACT EVALUATION FINDINGS SNAPSHOT

HYPOTHESIS 1 - The blockchain application improves functionality of the value chain by improving transaction efficiency and the flow of information between actors.

The nature of BCT creates an approach to strengthening an entire value chain simultaneously as the app requires all nodes of actors to be engaged in transacting, compared to other apps that are used by single nodes alone. Transaction costs, cooperation, and access to information improved over the six-month period of evaluation.

HYPOTHESIS 2 - Improved functionality of the value chain will increase incomes of value chain actors, especially women and youth.

Improvements in value chain functionality due to the BCT app led to an improvement of producer incomes, especially for women, from on-farm activities; however, traders' income decreased across all sources of income, while retailers' income increased from on-farm activities and employment.

HYPOTHESIS 3 - Increased incomes of value chain actors and increased availability and desirability of AIVs, lead to improved food security among value chain actors.

There was clear evidence that food security did increase over the 6-month study period. Households demonstrated an ability to purchase higher quality proteins and fruits when compared with the baseline. In addition to increased income, the focus of the project on the nutritional quality of AIVs and how to use these characteristics to market the product to consumers also helped to increase the demand of participants for the leafy greens.

HYPOTHESIS 4 - In retail outlets, the blockchain application will improve the marketability of AIV varieties.

This study revealed that vegetable quality and information about how the vegetables were produced were important factors shaping purchasing decisions. BCT created an incentive for producers to increase the marketability of AIVs. Consumers perceived a significant increase in the quality and availability of AIVs from the baseline to endline, but still had limited access to information on the inputs used in the production of AIVs, production practices, water quality, and the transportation methods of the vegetables.

HYPOTHESIS 5 - In retail outlets, the blockchain application will improve the marketability of AIV varieties by addressing gendered factors that influence food purchase, preparation, and consumption.

Over the 6-month study, retailers reported an improvement in the marketability of AIVs, including a willingness among consumers to pay a price premium – estimated to be as much as a 10 to 30 KES – for Grade A vegetables. There was also a self-reported increase in the volume of vegetables study participants purchased. For all participants, better quality was the leading factor driving the increase, followed by better prices and more awareness of the nutritional importance of AIVs.

HYPOTHESIS 6 - Value chain actors will be willing to pay a small fee for the blockchain application for the economic and nutritional benefits derived from its use.

Approximately 75% of producer, traders, and retailers indicated they were willing to pay 150 KES per month to continue to use the AgUnity app; however, to be willing to pay this price, the app would also need to offer complementary services and features, such as providing producers with access to micro or crop insurance, information on integrated pest control techniques, trainings, access to new markets for AIVs, etc.

Box 1. Overview of study findings

Impact Evaluation Outcomes

Hypothesis 1: The blockchain application improves the functionality of the value chain by improving transaction efficiency and the flow of information between actors.

Improvements in the functionality of the AIV value chain were observed between baseline and endline, with qualitative insights provided by the focus group discussions. Transaction efficiency increased as price and quantity variability was reduced, and coordination and cooperation between value chain actors increased as a result of enhanced trust between transacting parties. Flows of information improved in terms of transmitting the grade of the vegetable from producer through to end consumer; however, no other significant improvements in information transmission were observed.

Improved Transaction Efficiency

Price variability reduced

For transactions to be efficient, they must be reliable; meaning there is minimal variability and uncertainty in the agreed transaction quantity and price. The AIV value chain analysis conducted in the first phase of this study revealed transactions frequently changed after the initial agreement (Agnew et al. 2021). Figure 7 reveals that there was a decrease in the proportion of producers and traders that experience such variability; however, there was a slight increase in the proportion of retailers reporting variability.[6] Participants indicated that changes in the market and changes in demand were the main reasons that transactions varied. Traders also cited changes in supply as reasons for changes in the final transaction. There was no change in the underlying cause of variability between baseline and endline. The majority of producers (65%), traders (100%), and retailers (86%) confirmed that the AgUnity app was the reason that variability and uncertainty in transactions had been reduced in the last six months.

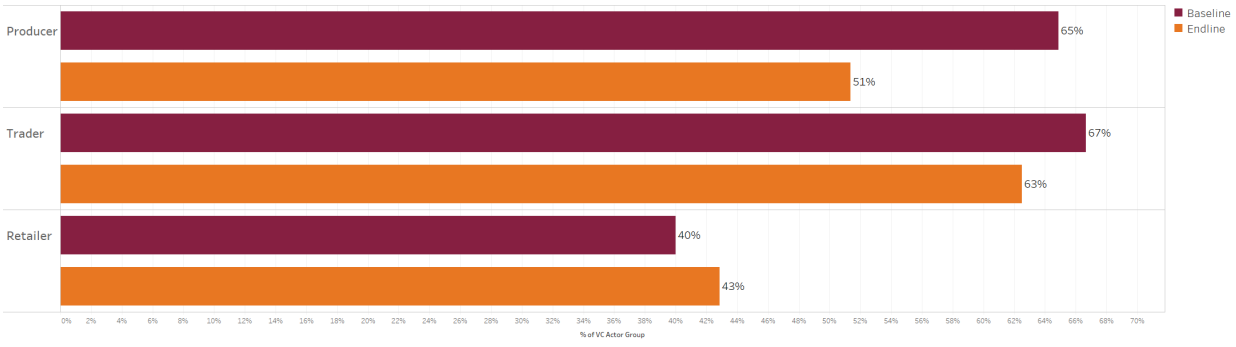


Figure 7. Transaction variability

The AgUnity app contributed to improving the reliability of transactions by increasing their precision, generating accurate and verifiable records, and creating a certainty of being paid (Table 3). Increased

[6] Producer p-value: 0.288; Trader p-value: 0.6875; Retailer p-value: 0.5075.

precision and quality of records are facilitated through the requirements to input an entry onto the blockchain, using the AgUnity app interface. When initiating a transaction, the buyer enters the quantity of the vegetable variety in kilograms along with its grade and total sale price. This is approved by the seller who then scans the buyer's unique QR code. Requiring the sale quantity to be specified in kilograms introduced standardization into the value chain; previously, vegetables were weighed by hand measure (see Agnew et al. 2021 for additional details). The record generated from the transaction is secure and immutable, meaning neither party can change it once it has been agreed upon. The precise and immutable transactions led to reduced disputes, increased purchase quantity, greater trust and transparency, and records available for informed decision-making.

Table 3. Reasons for reduced variability and uncertainty in transactions

Producer	Reduced uncertainty through precise transactions	7
	Certainty of being paid	5
	Buyers follow through on the agreement	3
	The price agreed upon is the price paid	2
	Reduced disputes in transactions	2
	Record of average market prices	2
	Improved relationships between value chain actors by increasing trust	2
	Transaction records are verifiable	1
	Quantity purchased has increased	1
	Prices are more fair	1
	Paid on the spot	1
	No longer sell on credit	1
	Increases awareness on profitability	1
	Improved transparency	1
	Enabled marketing vegetables online	1
	Accuracy has improved	1
	Able to collect on credit	1
Trader	Reduced transaction costs	2
	Quantities transacted are more precise	2
	Transaction records are verifiable	1
	Reduced uncertainty through precise transactions	1
	Record of average market prices	1
	Improved relationships between value chain actors by increasing trust	1
	Improve on transaction	1
	Has eased communication	1
	Easier to link with buyers	1
	Access to larger markets	1
Retailer	Record of average market prices	1
	Quantities transacted are more precise	1
	Knowlege of in-demand varieties	1
	Facilitates sales tracking	1

At baseline, only 30% of participants kept paper-based records and none used mobile technology for record-keeping. One producer shared, "*we never recorded our production or sales in whatsoever form before AgUnity.*" This limited the efficiency of transactions because, as one farmer put it, they were "*forgetting how* [they] *were transacting,* [such as the] *price and quantity.*"

PRIOR TO PARTICIPATING IN THIS PROJECT, ONLY 30% OF PARTICIPANTS KEPT RECORDS. BY THE END OF THE PROJECT, ALL PARTICIPANTS WERE USING THE AGUNITY APP TO GENERATE TRANSACTION RECORDS.

All participants, except for two, shared that the AgUnity app was extremely beneficial for record-keeping. The records created by the AgUnity app contributed to transactional efficiency by allowing sellers to easily track sales made on credit and reducing the time for repayment. Approximately 27% of producers, 63% of traders, and 29% of retailers indicated that the AgUnity app had helped them to collect their debts more efficiently than before. One trader said, "*now my retailer never fails to pay me as she always knows what needs to be paid, and I can ask anytime with certainty* [of what she owes]." Records also improved transactional efficiency by providing a record of previously agreed prices. This reduced negotiation and, according to traders and retailers, helped them set prices more fairly and consistently. By the end of the project, approximately 50% of participants listed the record-keeping functionality as one of the top three features of the AgUnity app.

Improved connectivity and coordination between actors

The AgUnity BCT-based app has demonstrated the potential to strengthen the entire value chain simultaneously by improving coordination between actors. For example, since transactions in the AgUnity BCT-based app can only occur between actors registered in the network, coordination and cooperation are required in order to transact. Furthermore, each user has access to a known group of individuals they can transact with, reducing the transaction cost of finding buyers. According to one producer, "*normally I had to hawk around the market for the whole day to find buyers. Now it is so swift. I know already who to trade veggies to and the buyer comes to fetch the goods*." One retailer shared during the focus group, "*it is beneficial to know a complete chain. One always knows who she/he should trade to, and can check down the stream*." This improved coordination ensures that high-quality, safe, and affordable products are delivered to local markets while minimizing transaction costs.

Beyond BCT, smartphone ownership also contributed to more effective coordination and efficient transactions. For example, one producer shared, "*I easily reach out to traders by phone and confirm* [the] *price and quantity, so I spend less time looking for buyers*." Another shared that they use WhatsApp to take pictures of the vegetables, which makes it easier to find buyers.

During the study's training and troubleshooting sessions, a shift in attitudes between the groups of actors was observed. Previously, there were feelings of frustration and resentment between actors

for not being treated fairly. As the study progressed, participants started to view themselves as a team working towards a common goal. One participant noticed this change. She shared during the focus group, "*everybody is now connected and active*." Another shared, "*everybody in the system is motivated as we are in a group*."

THE AGUNITY APP CONTRIBUTED TO SIGNIFICANT IMPROVEMENTS IN RELATIONSHIPS BETWEEN BUYERS AND SELLERS.

While there was no measurable change between baseline and endline in the number of producers who believed their buyers treated them fairly, 92% of producers and 87% of traders and retailers reported that using the AgUnity app improved their transacting relationships. These improved relationships and coordination between value chain actors contributed to a general preference for participants to transact with other AgUnity users (Table 4).

Table 4. Participant preference for selling to AgUnity versus non-AgUnity users.

To whom do you prefer to sell?	Producer	AgUnity traders	68%
		Don't know	15%
		Non-AgUnity traders	9%
		AgUnity retailers	6%
		Non-AgUnity retailers	3%
	Trader	AgUnity retailers	71%
		No Preference	29%
From whom do you prefer to buy?	Trader	AgUnity producers	86%
		No preference	14%
	Retailer	No preference	86%
		AgUnity traders	14%

When asked if the AgUnity app made it easier to cooperate with other value chain actors, and if so, who, at least 80% of each VC actor group confirmed it was easier to cooperate by using the app (Figure 8). The most commonly cited reasons for this increased ease of cooperation include improved coordination between producers (19%), increased connectivity between all value chain actors (17%), improved information sharing (17%), and improved communication (15%).

		Producers	Traders	Retailers	Consumers	Other producers	Other retailers	Other traders	Other
Producer	Female		80%	50%	35%	90%			
	Male		88%	29%	18%	59%			
Trader	Female	71%		57%	29%			71%	
	Male	100%		100%				100%	
Retailer	Female	71%	71%				29%		14%

Figure 8. Improved cooperation between groups

Increased cooperation led to a reduction in AIV post-harvest loss and contributed to improved delivery of high-quality, safe, and affordable produce to local markets. Previously, producers used to harvest their vegetables and find sellers. Now producers find buyers for their vegetables before harvesting, so they only harvest what they can sell that day. One producer shared, "*we have now* [an] *assured market and we minimize our loss and wastage*." This efficiency has led to a reduction in profit loss, ensures producers are fairly compensated, and helps supply to better meet demand.

In addition to increased cooperation *between* groups of actors, there was also an observed increase in cooperation *within* groups of actors, particularly producers. In each study location, farmers organized themselves into legally registered self-help groups to strengthen their skills in using the AgUnity app, coordinate their production so they can more effectively meet demand in the market, and start a saving and loans fund. Producers also coordinated the varieties of AIVs produced and when they were sold so that the market is not flooded with one type of vegetable.

Enhanced trust between actors

The AgUnity app sought to improve trust between actors by verifying the identity of users and creating an immutable ledger of transactions stored on a public blockchain. Anecdotally, trust was strengthened as a result of using the AgUnity app, particularly between producers and their buyers. For example, one retailer shared that "*as the suppliers' and buyers' names are on the phone, you develop trust and consistency with the connection*." Another shared that they trust the records of the people they are transacting with because they know they cannot be altered or changed. Overall, there is "*a lot of trust between the players, we* [work to] *accommodate each other*" one producer said.

Figure 9. Average trust scores by value chain actor

Note: Grey circles represent the average trust score for on a 5-pt Likert Scale, where 1 is do not trust at all and 5 is completely trust. The width of the band in the figure represents the proportion of participants who selected the ordinal Likert response.

When examining the trust that value chain actors have towards various groups of stakeholders (Figure 9), there was no statistically significant change between baseline and endline, except for traders' reduced trust in creditors and an increase in retailers' trust in other retailers (all p-values exceed 0.1).

Improved Flow of Information

Information is integral to the functionality of agri-food value chains. It contributes to consumers' willingness to pay a price that fairly compensates value chain actors for their respective activities and ensures that demanded varieties of AIVs are consistently available in the market. The AgUnity BCT-based app facilitated the improved transmission of information on the grade of the vegetable which increased the prices producers received. Price signaling led producers to more effectively meet the demand for high-quality, popular varieties of AIVs. However, while BCT-generated records increased access to information for individual user groups, there was little improvement in the transfer of information from producer to consumer and consumer to producer throughout the study. This suggests there may be economic and efficiency gains still to be captured in AIV value chains.

Adoption of vegetable grades & standardization

According to the consumer midline survey responses, information on the date of harvest, use of pesticides, nutrition information, and recipes for the vegetables were important to consumers when deciding to purchase AIVs (Figure 10). While only 2 respondents were interested in grading information at the point of sale, 70% of consumers indicated they would pay a price premium of 5 to 50% over the current price of 100 KES per bundle of vegetables for Grade A produce, signaling their demand for high-quality produce.

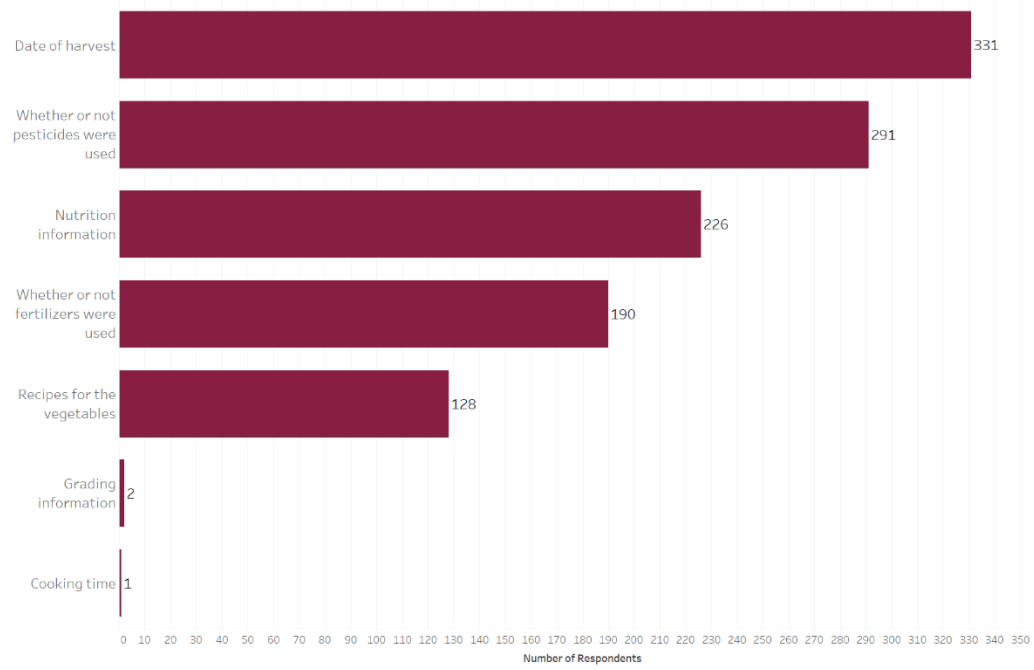


Figure 10. Information desired at the point of sale

Given BCT's ability to track information on bundles of products from farm to fork and the findings from the initial value chain analysis and consumer midline responses (Figure 10), it was collectively

decided with participants to grade the vegetables. With guidance from Dr. Joseph Mafura, an Egerton University professor in horticulture, and collaboration with all participants, a tool was developed to grade the AIVs into Grade A and Grade B (Appendix 1). Figure 11 shows the adoption of the grading process by producers and retailers between baseline and endline.[7] While the figure suggests that a majority of producers and traders were grading their vegetables prior to the study, the initial study trainings revealed that there was no official grading system in use.

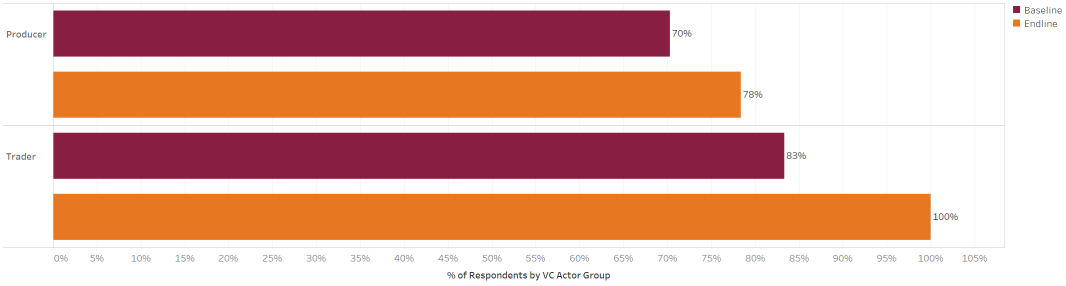


Figure 11. Grading of AIVs for sale

By the end of the study, **100% of traders** and **the majority of producers** were using the formal grading process designed in this study.

Figure 12. Retailers differentiating grades of vegetables

Using the grading system and the BCT-based app to transmit this information along the value chain was highly accepted by project participants. For example, one producer noted, *"with the standard quality and clear communication about Grade A, it is really easy to sell.* [Its] *very efficient*." By the end of the study, approximately 60% of retailers were marketing different grades of vegetables at their stalls (Figure 12).

The independent evaluation of consumers in the study markets found that of the consumers who have started purchasing more AIVs in the last six months (n=35, 56%), 20% did so because Grade A vegetables were now available in the market. Of those same consumers, 92% were purchasing more because the quality of the vegetables had improved. This improvement was an outcome of producers realizing the improved prices they can obtain from high-quality, Grade A produce, which is reinforced by the records stored on their phones.

[7] Producer p-value: 0.0006; Trader p-value: 0.0309.

Figure 13. Producers and study personnel pictured with the market stall poster

The initial value chain analysis and consumer baseline survey revealed that consumers also want to know more about the producers growing the vegetables and their farming practices. While BCT enables this traceability, smartphone ownership is not prevalent among consumers, limiting their access to information stored on the blockchain. While options are explored on how to provide consumers without a smartphone with access to blockchain-based data, we created posters that provide pictures of their suppliers and the production practices used in growing the vegetables (e.g., grown without the use of pesticides, organic fertilizers used, etc.) for retailers to attach to their market stalls (Figure 13). These posters introduce the idea of traceability into informal, open-air markets in peri-urban areas of Kenya. In markets where consumers own smartphones, this information could be accessed directly from the blockchain by scanning a QR code or entering a lot number. In addition to providing information demanded by consumers, this data is valuable to producers as well. One producer shared, "*It is exciting to be known. The struggle is worth it to keep on selling the vegetables and we are proud of it.*" Another shared, "*we feel happy and that we are known for our AIV produces*."

Increased access to information

For popular varieties of AIVs to be consistently available in the market, producers must view the production of the leafy vegetables as worthwhile. The AgUnity app and the records it generates help producers track revenues and quantities of each AIV variety sold (Figure 14). One producer shared that she now understands how much she is making from the sale of their vegetables because of the records stored in the app's wallet. This information helped her realize it is worth her time to continue vegetable production.

Figure 14. Screenshot of AgUnity app wallet

Before participating in this study, only a portion of those keeping records used them in decision making. By November 2021, the majority of participants, particularly producers, were using records in decision making (Figure 15) on varieties and quantities to plant, when to harvest the vegetables, traders and retailers to sell to, and means to reduce post-harvest loss, etc.[8] In conjunction with improved

[8] Producer p-value: 0.237; Trader p-value: 0.5078; Retailer p-value: 0.7539

coordination and cooperation between value chain actors, these changes resulted in an improved supply of quality AIVs to retailers.

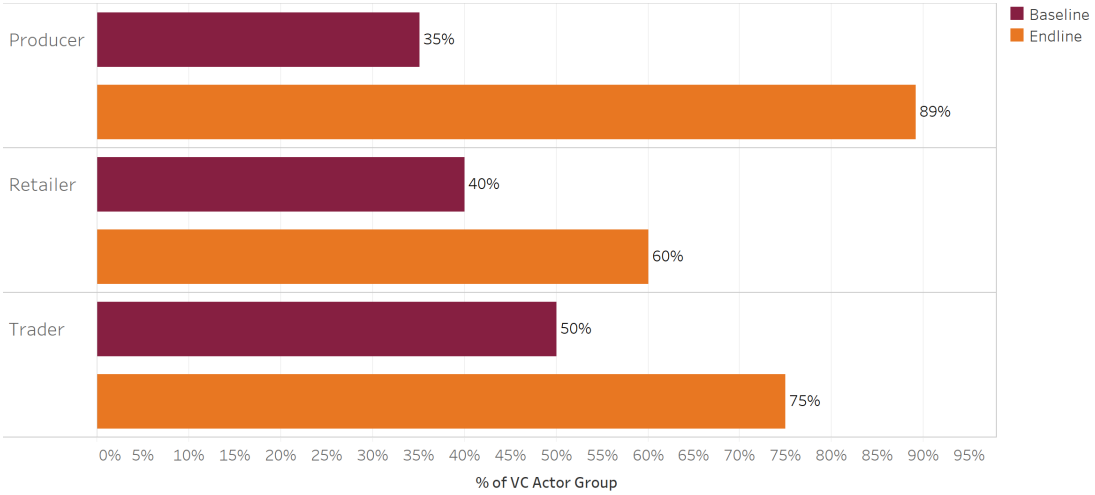


Figure 15. Changes in the use of records for decision making

Figure 16 shows the difference between retailers' access to an adequate supply of demanded AIVs between baseline and endline. African black nightshade, spider plant, cowpeas, and amaranth are the most popular varieties of AIVs among participants. There was a reduction in the number of retailers who face difficulty in sourcing these varieties.[9] One retailer shared that before participating in the study, she had regular difficulty in accessing the vegetables that consumers demanded; now she does not and has the produce she needs to stock her outlet.

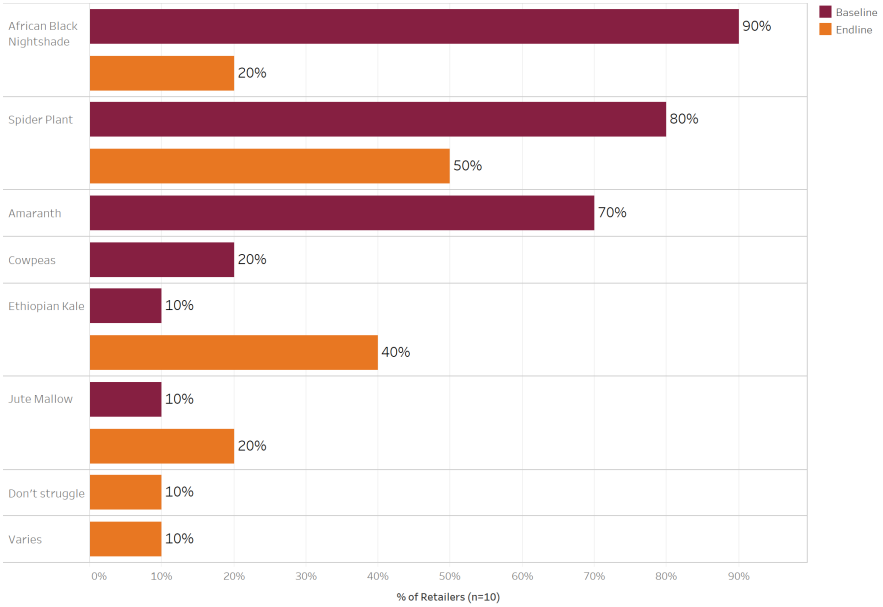


Figure 16. Proportion of retailers with difficulty accessing demanded AIV varieties

[9] African black nightshade p-value: 0.6072; Spider plant p-value: 0.3877; Amaranth p-value: 1.0.

While there has been a notable increase in access to information on the quality of vegetables and practices used in their production as a result of the BCT record generation and traceability, it is not apparent that the flow of detailed information regarding AIV production and demanded characteristics have improved between actors. Figure 17 and Figure 18 show the flow of information from producer to consumer and consumer to producer. The width of the bands represents the number of individuals who indicated they share the information type with people they are transacting with.

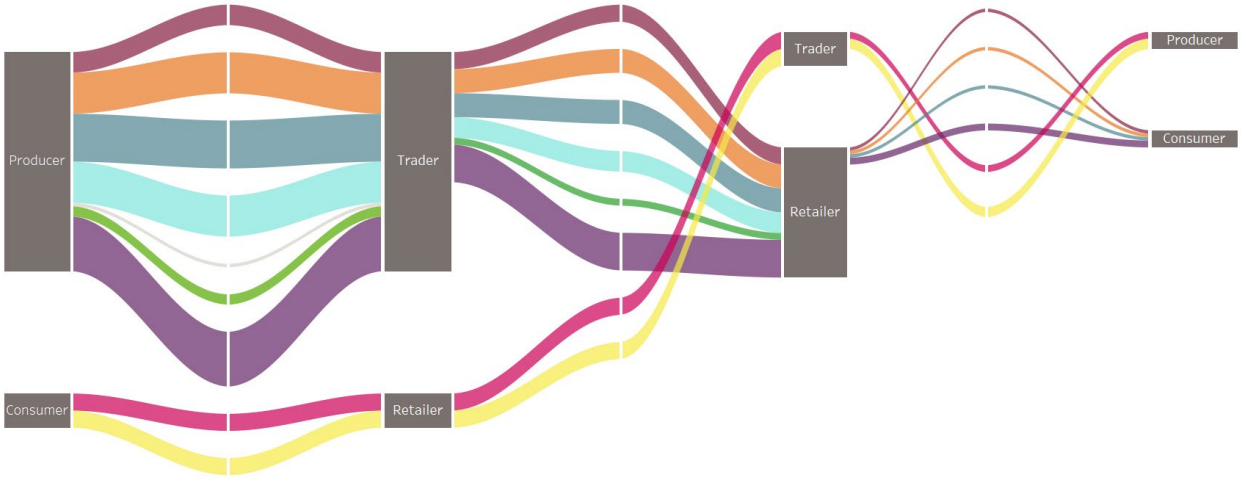


Figure 17. Flow of information from producer to consumer - baseline

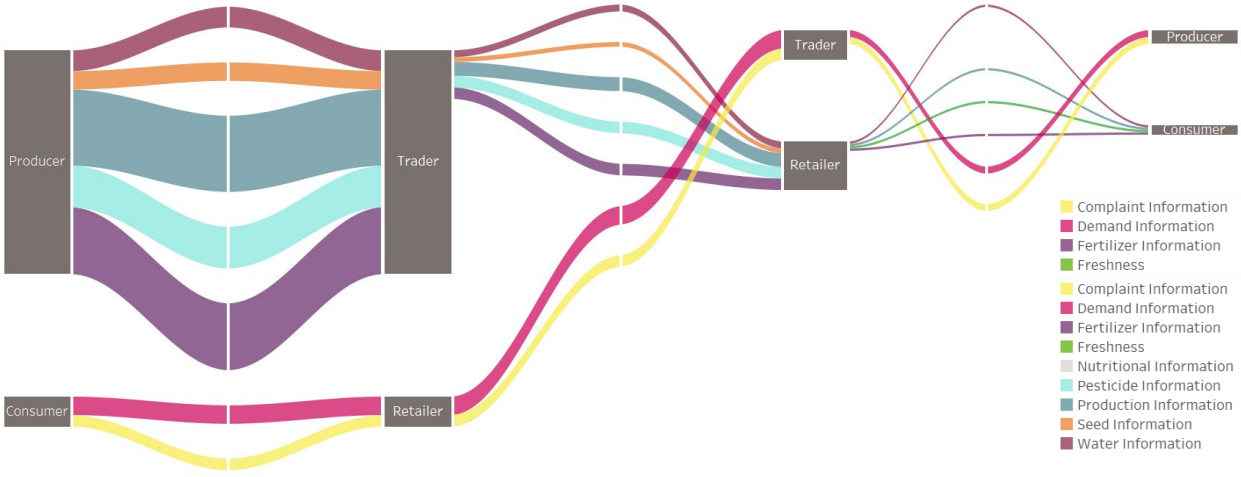


Figure 18. Flow of information from producer to consumer - endline

By the endline, producers were sharing more information on production practices with the trader. At both baseline and endline, the flow of information is impeded as it is passed through traders and retailers, though the reduction in band size should be interpreted with caution as there are fewer traders and retailers that participated in the study than producers. Regardless, only two to three

traders share information that they receive with retailers and information they receive from retailers with consumers. Responses from consumers in the market match the information retailers indicated they pass on to their buyers. The most common information shared with consumers includes the date of harvest (100%), production methods (70%), grade (60%), and harvest methods (30%), but the majority of consumers still do not have access to information about the AIVs.

Access to new markets

Offering vegetables *with information* rather than vegetables coming from opaque value chains has also opened opportunities to reach new markets that are currently undersupplied with AIVs in Kakamega and surrounding counties. The *New Vision* CBO will be able to supply the supermarket chain, Quick Mart, in Kakamega and Kisumu with their vegetables. Quick Mart was very interested in the traceability and transparency that BCT facilitated in the AIV value chains. An in-store display was developed (Figure 19) that will allow shoppers to scan a QR code that will take them to a website with information about the farm-to-store journey of the vegetables.

Figure 19. Quick Mart in-store display

Six-month status update

Since the end of the LASER PULSE funding, the CBO New Vision continues to scan each transaction with their farmers. In addition to offering AIVs to institutional buyers (such as hotels) out of their office location, they have started a **formal relationship** to sell AIVs to SNV's *Veggies for People and Planet Project* at **a profit of 20 KES per kilogram**. Earning a profit will allow *New Vision* to provide additional services to their buyers, including acting as an off-taker and buying their vegetables in bulk each week.

Hypothesis 2: Improved functionality of the value chain will increase the incomes of value chain actors, especially women and youth.

The improved functionality of the AIV value chain led to an improvement in income for producers, especially women; however, the incomes of traders and retailers decreased compared to the same months the previous year. Only three youth (one producer, one trader, and one retailer) participated in this project due to enrollment constraints. In both quarters, youth reported an increase in income.

Improvement in Producer Incomes

Improvements in value chain functionality resulting from the AgUnity blockchain-based application led to an improvement in producer incomes from on-farm activities; however, traders' income decreased across all sources of income, while retailers' income increased from on-farm activities and employment. Figure 20 compares the average income reported by each actor type from April to June (Quarter 2) and July to September (Quarter 3) in a typical year (baseline) and after using the AgUnity app (endline). During Quarter 2, producer average on-farm income increased by 32% (p-value: 0.184), and by 25% in Quarter 3 (p-value: 0.286). Their average total income increased by 26% and 5%, respectively (p-value 0.356; p-value: 0.879). Contrastingly, traders' income decreased across all sources of income, while retailers' income increased by 80% from on-farm activities and 86% from employment between April and June (p-value: 0.559) and 86% between July and September; however, average total income decreased by about 20% during both quarters (p-value 0.584).

	April to June Average Income						July to September Average Income					
	Producer		Trader		Retailer		Producer		Trader		Retailer	
	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline
On-farm income	10,994	14,567	17,250	5,667	4,400	7,917	14,355	17,873	19,750	8,083	5,600	5,417
Off-farm income	4,833	5,150	37,750	16,813	47,000	28,000	4,833	4,954	22,000	18,394	45,222	25,028
Employment	2,739	1,962	0	0	12,000	22,417	2,391	1,962	0	0	12,000	22,417
Remittances	1,000	1,240	0	0	0	0	975	1,240	0	0	0	0
Total Income	16,963	21,427	46,000	21,857	69,375	55,333	22,935	23,912	35,400	27,786	63,750	50,533

Figure 20. Average income by quarter and activity

Female producers experienced a larger increase in average total income in Quarter 2 (Figure 21) and Quarter 3 (Figure 22) than male producers, who experienced a decrease in average total income in

both quarters. While male producers had a larger increase in on-farm income, female producers brought in more income from off-farm and employment activities, contributing to a larger total increase in income. This difference may have resulted from the time savings created by using the AgUnity app. For example, one producer shared, "*I can use my time to work on other crops, to be* [a] *better mother, and serve the community*." The increase in on-farm income among men may have resulted from increased participation in AIV production or the obtaining of livestock from increased income from the sale of AIVs.

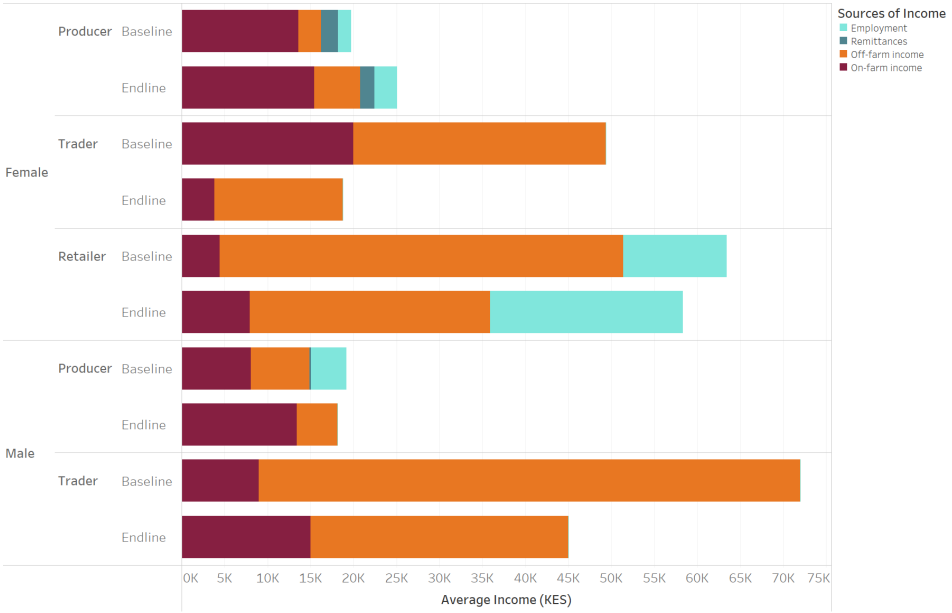


Figure 21. Changes in average income by gender, April – June (Quarter 2)

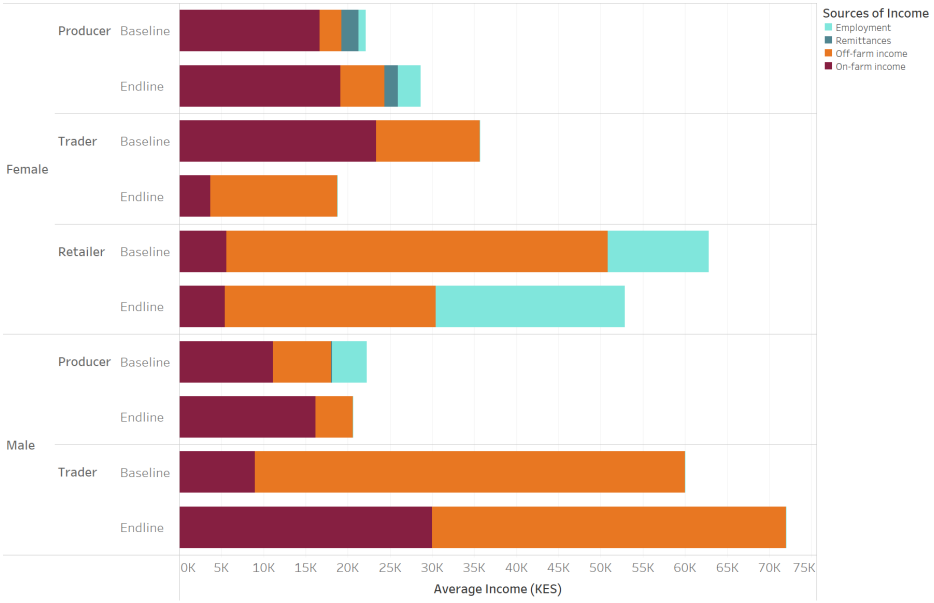


Figure 22. Changes in average income by gender, July – September (Quarter 3)

TIME SAVINGS CREATED BY THE AGUNITY APP LED TO IMPROVED, DIVERSIFIED INCOME FOR WOMEN.

Part of this increase in income was derived from an increase in the sale of AIVs. Approximately 85% of producers, 75% of traders, and 43% of retailers indicated that their income from trading in AIVs had increased over the last six months. Approximately 67% of producers, 87% of traders, and 57% of retailers felt that the records generated from the AgUnity app contributed to an improved income.

Improvement in Youth Income

While only three youth participated as users in this project,[10] each reported an increase in income in both quarters of the study period compared to the same months in the previous years. The producer's on-farm income increased by 20% in Quarter 2, 40% in Quarter 3, and was able to diversify into off-farm income earning activities (Figure 23, Figure 24). The trader's income increased by approximately 300% in Quarters 2 and 3 with no income reported at baseline. The retailer's income increased by approximately 300% in Quarter 2 and 750% in Quarter 3, similarly with no income reported at baseline.

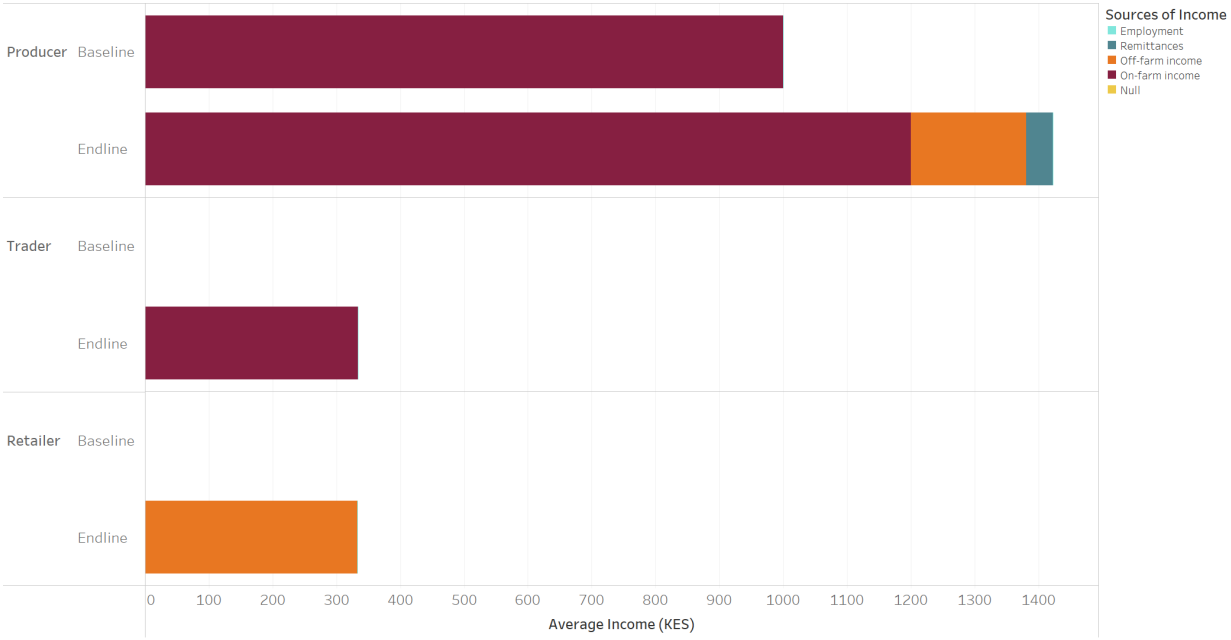


Figure 23. Changes in average income among youth, April – June (Quarter 2)

[10] The method of recruitment to ensure all parties transact with one another in each of the value chain arrangements constrained the number of youth that could be engaged in this project as users of the phone since youth participation in agriculture is low in Kakamega County.

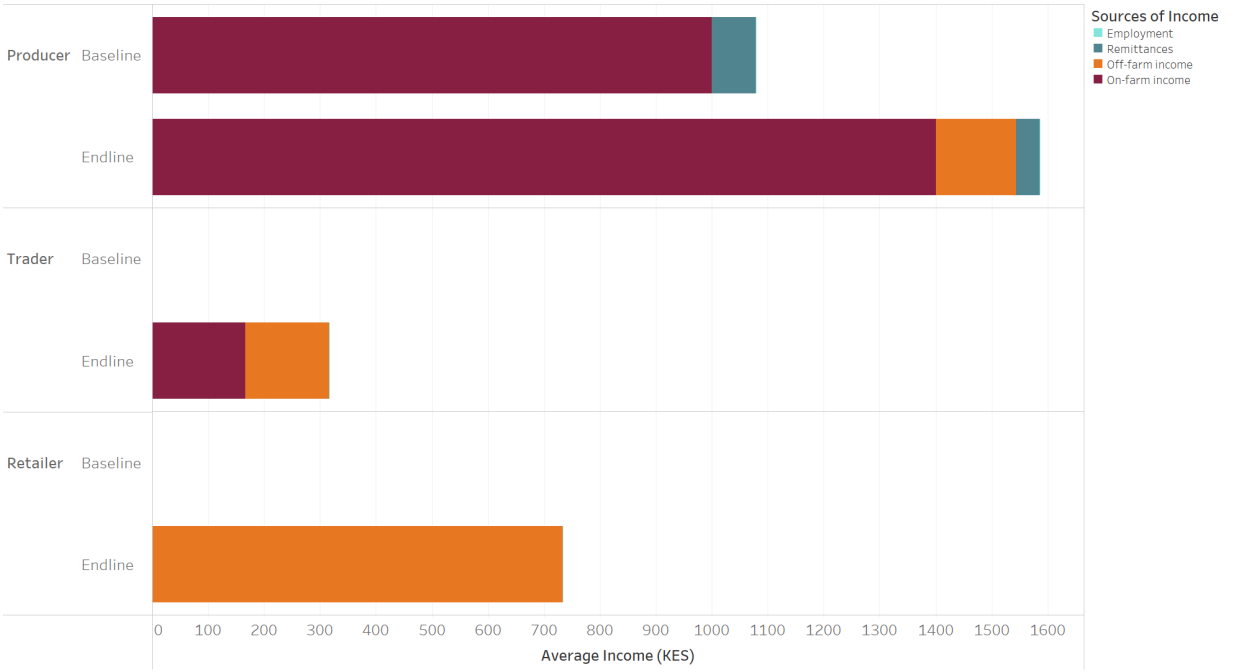


Figure 24. Changes in average income among youth, July – September (Quarter 3)

Six-month status update

The producer youth was appointed by the producers in his value chain group to serve as an **'AgChampion.'** This role was designed by AgUnity to ensure that farmers had support in learning how to use the app and to create functional feedback loops. Because of this youth's leadership role in the project and use of technology in his operation, more than **150 youth in his sub-county** are now interested in **participating in the AgUnity network and re-engaging in agriculture**. Some of these youth had no interest in agriculture until they saw this AgChampion's success with his operation and the fair market linkages that the app creates.

Contributors to Improved Income

The factors that value chain actors perceived as contributing to improved income are summarized in Table 5. Producers increased the volume of their production by organizing themselves into groups and pursuing training to improve yields and the quality of vegetables produced. This allowed producers to transact higher volumes of Grade A vegetables which led to higher prices for AIVs. Traders also perceived that they were also able to get better prices for the AIVs from the retailers.

Table 5. Why has income increased from transacting in AIVs?

Producer	Increased volume of production of demanded AIVs	26
	Increased price per variety	14
	Increased volume per sale	10
	Increased frequency of transaction	6
	Always able to find a buyer	6
	Other	2
Trader	Increased volume per sale	4
	Better prices from retailer	4
	Always being to find a buyer	3
	Always being able to find a seller	3
	Increased frequency of transaction	2
Retailer	Selling Grade A vegetables	3
	Increased volume per sale	2
	Better prices	2
	Increased volume of production of demanded AIVs	1
	Increased frequency of transaction	1
	Always able to find sellers	1
	Always able to find buyers	1

Increased production of quality AIVs

Of the 70% of producers (n=26) that indicated that increased income resulted from increased production, 74% of female producers cited higher volumes of production (n=10) compared to 65% of male producers (n=7). Figure 25 summarizes the average increase in production by variety with the number of producers that cited an increase in production of that variety.

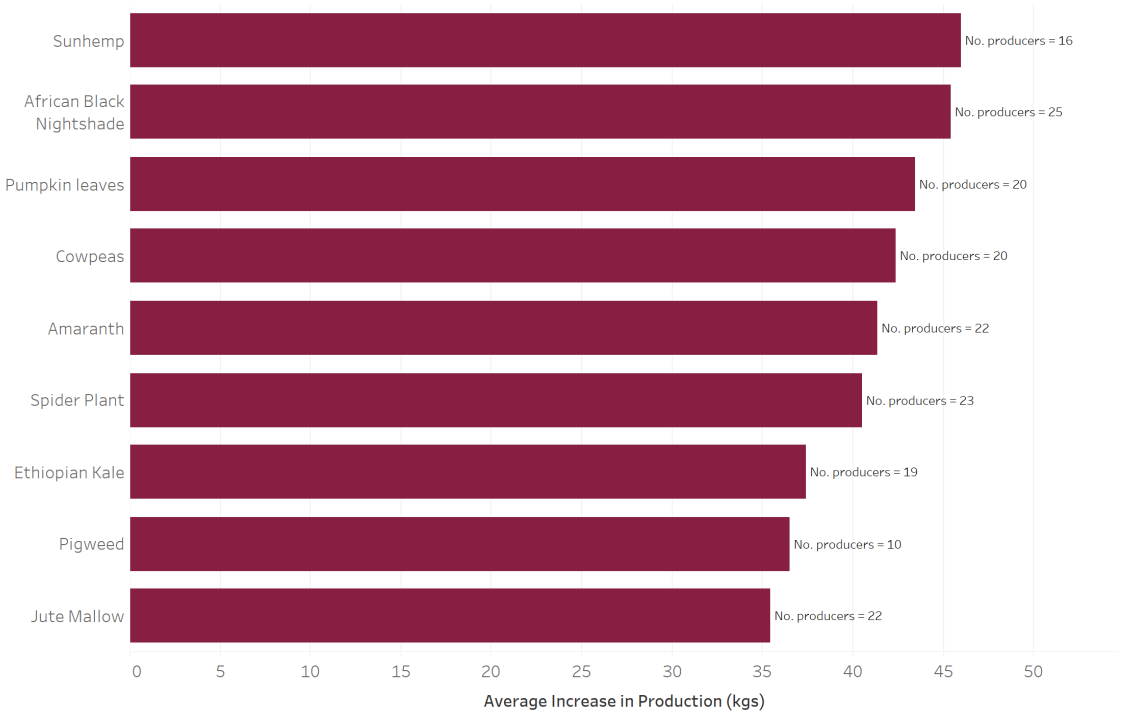


Figure 25. Average increase in production by variety

This increase in production was achieved by improved production practices since producers realized they could earn a price premium for higher quality vegetables. Improvements in coordination within and across groups of actors in the AIV value chain enabled groups to seek training to improve the quality of their AIV production, recognizing the price premium that Grade A vegetables offer. One producer emphasized the importance of this training stating, *"the training about production, quality, grading and how to produce organic vegetables really help[ed] our productivity*." Some of this training was provided through the study of how to maximize the benefits of BCT. Value chain actors were taught about how to ensure traceability of the different grades and how to market these to the consumer. Increased income has also allowed producers and producer groups to invest in expanding their production. One producer said, "*as a group now we look for land to lease on the riverbank to increase our production yield*."

Higher prices for AIVs

Roughly half of producers and traders, and a third of retailers, perceived they were getting better prices for AIVs as a result of using the AgUnity V3 SuperApp because they were able to trace the grade of the vegetable. For example, one trader said, "*other retailers* [in the market] *already know about Grade A vegetables and are willing to pay more* [as well]." When asked why the price increased, the majority of producers cited increased demand and better quality of vegetables (Table 6).

Table 6. Perceived reasons for improved prices

More demand	10
Better quality	10
Seasonal price change	8
Improved negotiating power because of the phone/app	7
More information about prices resulting from the phone/app	6
Other	1

Figure 26 shows that prices increased for cowpeas and Sunn Hemp, while they decreased for amaranth and pumpkin leaves. However, as Figure 27 shows, the quantity and amount paid to the seller of the varieties transacted over the study period (cowpeas, Sunn Hemp, pumpkin leaves, and amaranth) increased. Thus, the sellers may perceive they are receiving better prices, even though the average price per kg decreased for amaranth and pumpkin leaves. These data were obtained from the transactions that were recorded on the AgUnity app.

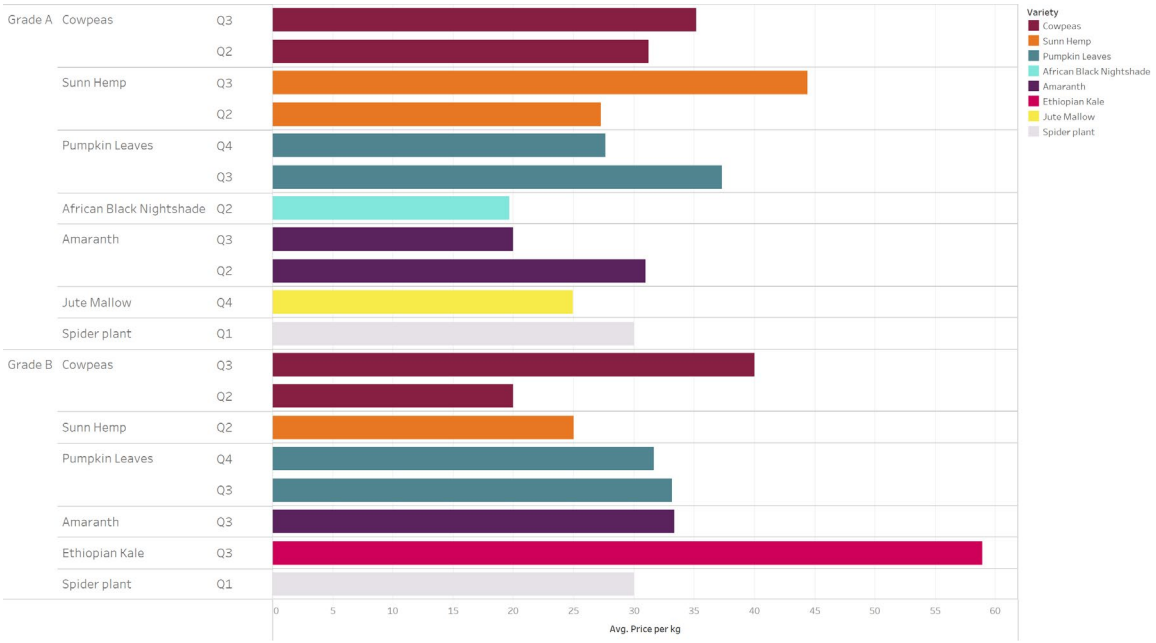


Figure 26. Average price per kilogram by variety, quarterly

Figure 27. Amount received in shillings and quantity sold in kgs, quarterly

Diversification of income-earning opportunities

Increased income from AIV production has created access to other types of economic opportunities. For example, one producer said that the additional income earned by her producer group enabled them to acquire land to start growing sweet potatoes. About 50% percent of producers have also indicated they have been able to acquire livestock such as local chickens (n=18), local cows (n=7), local goats (n=5), improved cows (n=2), and sheep (n=2).

Not all opportunities to diversify income had materialized by the end of the project; however, the improved coordination and cooperation within and across value chain actors have helped orient participants towards identifying diversification opportunities. For example, the CBO intends to explore other revenue-generating activities, such as producing and selling compost tea or selling agricultural inputs, which would allow them to provide training for their members and assist them in growing their production and market access.

Hypothesis 3: Increased incomes of value chain actors lead to improved food security at the household level.

There was clear evidence that food security did increase over the 6-month study period. Value chain actors (i.e., producer, trader, retailer) demonstrated an ability to purchase higher quality proteins and fruits when compared with the baseline. In addition to increased income, the focus of the project on the nutritional quality of AIVs and how to use these characteristics to market the product to consumers also helped to increase the demand of participants for the leafy greens.

Reduction in Experiences of Food Insecurity

Table 7 shows that the average food insecurity experience scale (FIES) score for producers, traders, and retailers decreased over the study period, though the changes were not statistically significant. Scores closer to zero represent less severe food insecurity experiences.

Table 7. Average Food Insecurity Experience Scale (FIES) score

	Producer	Trader	Retailer
Baseline	2.9	5.5	4.2
Endline	2.4	3.4	2.0

Figure 28 breaks down the responses to the FIES items based on gender. For all items, a larger proportion of women compared to men reported these experiences. Reported instances of these food insecurity experiences decreased for all items except for 4 additional women who reported that their household ran out of food. The greatest decrease occurred for female value chain actors who were hungry but did not eat, reducing from 42% to 11%. There was also a 20% decrease in the number of women who only ate a few types of food and a 17% decrease in the number of women who ate less than they thought they should.

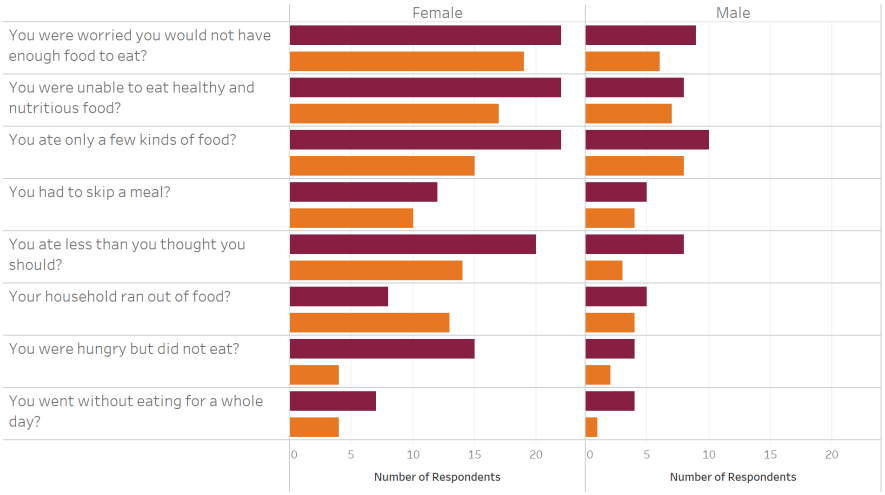


Figure 28. Respondents to FIES items by gender

Diet Diversity Score (DDS)

As shown in Table 8, there was no significant increase in diet diversity. For female traders, the average diet diversity score (DDS) decreased by almost 1 point and male traders' average score decreased by 0.5 points. Male traders' average DDS is higher than female traders, but there is no statistically significant difference between male and female producers (all p-values greater than 0.1).

Table 8. Average DDS by value chain actor and gender

		Baseline	Endline
Female	Producer	4.6	4.1
	Retailer	6.2	5.6
	Trader	4.4	3.6
Male	Producer	4.5	4.0
	Trader	5.0	4.0

According to reports of consumption of 12 food groups in the previous 24 hours, the number of households reporting consumption of leafy green vegetables decreased between baseline and endline. In fact, there was a decrease in the number of households reporting the consumption of several food groups including grains, roots and tubers, dairy, flesh foods, shellfish or fish, vitamin A-rich fruits and vegetables, other fruits, eggs, fat, and sugar (Table 9). However, as shown in Table 10, there has been an increase in the number of households who purchase dairy, legumes and nuts, and fruits (vitamin A rich and others).

Table 9. Foods consumed in the previous 24 hours

	Baseline	Endline
Grains	50	47
Roots and tubers	25	20
Dairy	45	36
Legumes and nuts	17	25
Flesh foods	9	4
Shellfish or fish	14	6
Dark green leafy vegetables	39	35
Vitamin A rich fruits	14	16
Vitamin A rich vegetables	14	7
Other fruits	9	2
Other vegetables	14	12
Eggs	8	7
Fat	34	29
Sugar	49	41

Table 10. Foods purchased

	Baseline	Endline
Grains	23	23
Roots and tubers	7	7
Dairy	16	19
Legumes and nuts	5	13
Flesh foods	4	10
Shellfish or fish	17	16
Dark green leafy vegetables	5	2
Vitamin A rich fruits	8	13
Vitamin A rich vegetables	4	4
Other fruits	8	9
Other vegetables	7	4
Eggs	6	6
Fat	33	31
Sugars	37	37

Increased Vegetable Consumption

Despite the fact that the dietary recall indicated that consumption of leafy greens decreased over the study period, 92% of producers, 88% of traders, and 100% of retailers indicated that the quantity of indigenous vegetables consumed in the household increased during the previous six-month period. The most common reasons cited for this were increased production (42%) and the fact they are now producing a surplus (14%), increased awareness of nutritional importance (21%), and increased preference for vegetables (11%). Increased awareness of the nutritional characteristics of indigenous vegetables was commonly shared by participants during the endline focus groups. According to one participant, "*we consume AIV more than before as we understand its nutritious quality* [now]."

Hypothesis 4: In retail outlets, the blockchain application will improve the marketability of AIV varieties by addressing gendered factors that influence food purchase, preparation, and consumption.

Of central concern to both women and men is the availability and quality of the AIV varieties they are looking for – both of which increased over the study period. There was also a small increase in access to information about the vegetables and how they are produced, which is particularly important to women. Over the study period, the awareness of the nutritional importance increased among both men and women; however, a relatively small percentage learned of the nutritional characteristics of AIVs from the retailer they purchase from.

Gendered Factors that Influence Food Purchase, Preparation, and Consumption

At baseline, consumers in the five study markets were asked what factors would be likely to contribute to increased AIV purchase, preparation, and consumption. Quality of the vegetables, availability of preferred varieties, knowledge on how to prepare the vegetables, quantity, and information on how the vegetables were produced were all important factors to consumers. Figure 29 demonstrates that the male and female responses were similar. There are some small differences though; for example, more men than women indicated that more money would be required to purchase AIVs, and increased quality and quantity of vegetables needed to be available. More women than men indicated that the varieties they prefer needed to be more available and that they wanted more information on how the vegetables were produced.

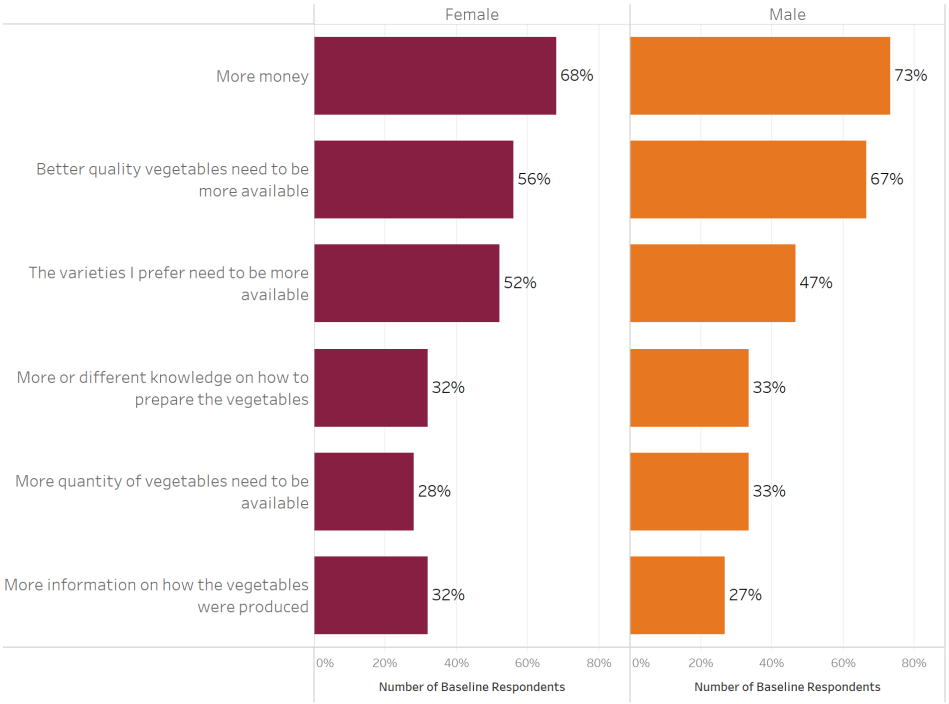


Figure 29. Factors that could increase AIV purchase

The consumer midline survey (n=366) confirmed that quality and information about how the vegetables were produced are important factors in the purchasing decision (Figure 30).

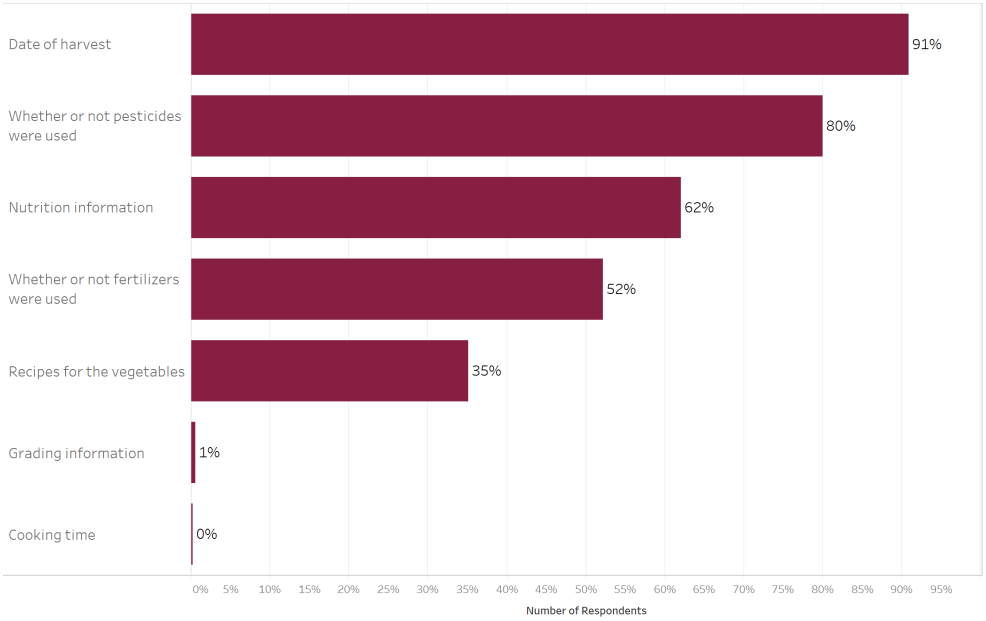


Figure 30. Consumer preference for information about AIVs

Quality

Consumers were asked during the baseline and endline to rank the quality of vegetables they were able to purchase in local markets. As Table 11 shows, there was an approximately 60% increase in the proportion of men and women who perceive vegetable quality as excellent. By the endline, neither women nor men perceived the vegetable quality as poor.

Table 11. Ranking of AIV quality

	Female		Male	
	Baseline	Endline	Baseline	Endline
Excellent	20%	81%	20%	78%
Good	48%	13%	20%	22%
Average	28%	6%	60%	
Poor	4%			

When asked directly if vegetable quality had specifically improved over the last 6 months compared to other periods, 94% of respondents answered yes.

Availability

AIV availability is largely determined by season. Leveling out the fluctuations in availability is essential for capturing economic and food and nutrition security benefits. Table 12 shows that the availability of AIVs increased during the six months of the study in the focus markets, despite a drought that was affecting agricultural production in the region. By the end of the study, 100% of both men and

women agreed that the AIV varieties they were looking for were available in the market; however, approximately 6% of women indicated that when they were available, they were too expensive.

Table 12. Availability of preferred AIVs in the market

	Female		Male	
	Baseline	Endline	Baseline	Endline
Yes	68%	100%	87%	100%
No - they are not available	28%		20%	
No - they are too expensive	16%	6%	7%	

Food safety

Guarantee of the safety of AIVs is central to the consumer's decision to purchase and consume leafy greens. According to one retailer, "*the consumer wants to know for sure what's been … used* [in the production of the vegetables] *and it requires trust*." Table 13 shows that access to information about AIV production and food safety has only increased slightly among consumers since the beginning of the project. Access to information about the vegetable grade has increased, especially for female consumers. The proportion of consumers with no access to information about their vegetables decreased by about 25% for both men and women; however, consumers still have little access to information on the inputs used in the production of AIVs, production practices, water quality, and the transportation methods of the vegetables.

Table 13. Access to AIV information

	Female		Male	
	Baseline	Endline	Baseline	Endline
Date of harvest		37%		13%
Fertilizer type	8%		7%	
Fertilizer usage	4%		7%	
Grade	8%	17%	7%	6%
Harvest methods		3%		13%
Production methods		13%		19%
Seed type	4%	17%		13%
Transportation method				6%
Water quality used in production	4%			
None	80%	53%	93%	69%

Cultural and nutritional importance

AIVs are also important cultural vegetables as they are part of the Kenyan cuisine, served alongside ugali (a thick porridge made from maize meal) and fish or chicken, particularly in rural areas. They also have gendered roles in their preparation. Consumers were asked the extent to which they agreed with the cultural importance and preparation of the vegetables at baseline and endline (Table 14). Women originally held a much stronger belief than men around AIVs and their cultural

significance; this changed significantly for men between baseline and endline. Women also more strongly believed that AIVs have positive nutritional benefits; however, this too significantly increased throughout the study among men. Generally speaking, there is a confidence that both the respondent and the respondent's spouse can prepare AIVs; there is a substantial improvement in the confidence of women that their spouse can prepare the AIVs between baseline and endline. There is also a consensus among both men and women that AIV producers should be supported.

Table 14. Cultural and nutritional perceptions of AIVs

		Female		Male	
		Baseline	Endline	Baseline	Endline
AIVs are an important cultural food	Strongly agree	88%	81%	60%	94%
	Agree	12%	19%	33%	6%
	Somewhat agree			7%	
AIVs contribute positive nutritional elements to the diets of household members	Strongly agree	92%	84%	67%	82%
	Agree	4%	16%	20%	18%
	Somewhat agree			7%	
I do not know how to prepare vegetables/recipes that include the vegetables	Strongly agree		3%	7%	
	Agree		6%	7%	6%
	Somewhat disagree			13%	
	Disagree	100%	90%	73%	94%
My spouse does not know how to prepare/recipes that include the vegetables	Strongly agree	16%			
	Agree	12%	3%		
	Somewhat agree	8%			
	Neutral	12%			
	Somewhat disagree	8%			
	Disagree	36%	94%	87%	100%
Our household should increase the amount of AIVs we eat to improve nutrition	Strongly agree	72%	16%	53%	24%
	Agree	20%	81%	13%	71%
	Somewhat agree		3%	13%	6%
	Neutral			7%	
	Disagree	8%		13%	
We should support producers of AIVs	Strongly agree	60%	52%	67%	41%
	Agree	12%	45%	27%	59%
	Somewhat agree	28%	3%	7%	

When asked if the awareness regarding the nutritional quality of AIVs increased over the previous 6-month period, 84% of women and 67% of men indicated that it had; however, only 5% of respondents indicated that they had learned about the nutritional value of the AIVs from their retailer. When asked if their awareness of how to cook vegetables in ways that retain their nutritional value had increased, 97% of women and 67% of men said yes. Similarly, only 1 respondent had learned about this information from the retailer.

Hypothesis 5: Increased marketability of AIVs will translate into increased purchases of AIVs by low-income households.

The markets that were selected for this study primarily serve consumers in the third- and fourth-income quintiles. According to retailers, participating in the network of value chain actors using the AgUnity BCT-based app has improved the marketability of AIVs. This was primarily because the quality of the vegetables increased, and retailers were able to market vegetables from AgUnity producers as Grade A. One retailer stated, "*knowledge about grading and quality is easily accepted by the consumer. There's no challenges to communicate.*" Another said that "*most consumers appreciate the grade and are willing to accept the premium price* [for Grade A vegetables]." This was supported by the consumer midline, which revealed that there could potentially be as much as a 10 to 30 KES price premium for grade A vegetables.

As Table 15 shows, there has been a self-reported increase in the volume of vegetables purchased in the last 6 months. A slightly larger proportion of women compared to men reported increasing the quantity of vegetables purchased.

Table 15. Increase in AIV purchase over the previous 6-month period

	Female	Male
Yes	74%	61%
No	26%	28%
Not sure		11%

Figure 31 outlines the reasons for this increase. For all participants, better quality was the leading factor driving the increase, followed by better prices and more awareness of the nutritional importance of AIVs.

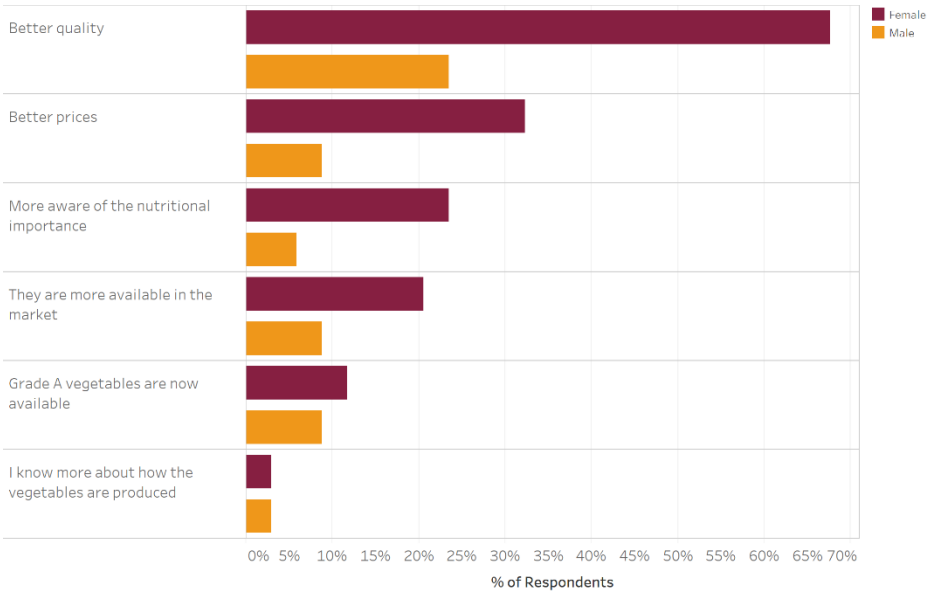


Figure 31. Reasons for increased purchase of AIVs

In addition to an increased quantity of AIV purchases, consumers spent more on average per week between baseline and endline on cowpeas, amaranth, and jute mallow. This is consistent with the price information collected from the AgUnity record-keeping app that indicated the increased prices were passed on to producers.

Table 16. Average weekly expenditure on AIVs (KES)

	Baseline	Endline
Cowpeas	58	66
Amaranth	48	60
Jute Mallow	52	53
African Black Nightshade	119	79
Spider Plant	110	68
Ethiopian Kale	51	30

Hypothesis 6: Value chain actors will be willing to pay a small fee for the blockchain application for the economic and nutritional benefits derived from its use.

The value of the records generated by the AgUnity BCT infrastructure was clearly demonstrated by all participants; however, in order to be willing to pay the 150 KES needed by AgUnity to sustain service provision, participants indicated they would need to have access to complementary services. In addition to the willingness to pay for the app, participants also were willing to pay the full cost of the phone (USD 75) if they could have access to affordable repayment terms. Anticipated benefits and intention to use the AgUnity V3 SuperApp were mostly unchanged between baseline and endline, though a slight cooling-off effect was observed.

Willingness to pay for the AgUnity app

Approximately 75% of producers, traders, and retailers indicated they were willing to pay 150 KES per month to continue to use the AgUnity app; however, to be willing to pay this price, the app would also need to offer complementary services and features. One participant shared, "*I would pay more, about 50 KES, for additional services such as reports, or micro or crop insurance*." Table 17 summarizes the services that consumers were interested in. All participants in the final focus groups where this activity was conducted indicated that they were interested in complementary services. An applet providing weather information and the ability to market vegetables online were the most popular apps that could be offered in addition to the blockchain.

Table 17. Interest of participants in complementary services

Service	Number of Participants
Weather information	23
Online marketing	21
M-Pesa integration	16
Pest control consultation	8
Extension services	7
Transportation service location	7
Information on nutrition and recipes	5

Sentiments toward the AgUnity App

Prior to participating in the study, participants were asked about the expected value of the AgUnity app in their operations and the extent to which they were willing to incorporate its use into their operations. The questions were modeled after Michels, Bonke, and Mußhoff (2019) and the Unified Theory of Acceptance and Use of Technology (UTAUT). Initial (baseline) perceptions of the AgUnity app were favorable, and participants for the most part expressed a strong interest in its potential value, indicating they intended to use it in their operations. By the endline, there was a slight cooling

effect, with more users tending towards a moderate agreement with the use and impact of the app among the participants using the AgUnity phone (Figure 32).

Figure 32. Perceptions of using the AgUnity app
Note: A 5-pt Likert Scale was used to measure attitudes towards the AgUnity app.

Participants largely enjoyed using the AgUnity app for reasons related to BCT as well as the design interface. It was clear that users understood they could not alter the records and that the people they were transacting with could not alter theirs. This contributed to the trustworthiness of the records. Several participants shared that they knew they could trust the records because they had been verified by two people (themselves and the buyer/seller), meaning they were mostly free from mistakes. This differs from recording transactions on paper – which can be lost or have an error. Participants also appreciated that the app was in Swahili which helped increase usability.

Despite its many positive benefits, there are still some technical challenges that need to be addressed to improve the usability of the app. For example, one participant shared that at times "*scanning is quite challenging*." This occurs because of a reflection created in the sun that prevents the QR code from being scanned. One participant said that "*we have to find shade in order to be able to scan*."

Another challenge is the intuitiveness of the app for traders. Since AgUnity has historically worked with value chains centered around cooperatives, their system needed to be adapted to include traders. Thus, this new capability had not benefited from a prior deployment, so additional improvements may be needed to ensure traders have the same user experience as producers and retailers.

Participants had several ideas on how AgUnity could expand its network, which is critical for ensuring there are enough buyers and sellers in the system. One idea was for AgUnity phones to be available in the local shops or to have specific AgUnity retail outlets. Another idea was to work closely with community-based organizations whose members could be trained to provide support and onboard new users into the system.

Community Interest in Joining the Network

In addition to participants recognizing the value of using the AgUnity app and smartphone in performing their respective activities in the value chain, members of the participants' communities and social networks were also interested in joining the network. One of the youths participating in the project shared that his friends were getting interested in agriculture that used technologies such as the smartphone and AgUnity app; they recognized how much their friend's agricultural business had improved since joining the study.

All participants in the study shared that if they had to pay for the smartphone to use the AgUnity app, they would be willing to pay 8,500 KES (USD 75) and believe that others in their community who wish to join the network would pay the same. They estimated that this could be paid for over six months, perhaps needing a month or two longer to repay if they had to simultaneously pay for the AgUnity subscription fees.

Six-month status update

A field visit conducted in May 2022, revealed that there is a group of at least **150 youth** that have learned about the AgUnity V3 SuperApp and the benefits of blockchain-based record-keeping and value chain coordination. They are currently saving to be able to purchase a phone in order **to join the network**. The entirety of *New Vision* CBO's **120 farmers** is also interested in joining the network. AgUnity plans to pilot a kiosk operation in collaboration with *New Vision* to start incorporating these interested participants.

Gender Implications

In addition to investigating the outlined six hypotheses, this study was concerned with understanding how ICTs such as smartphones and blockchain technology might help women secure their place in the value chain as upgrading activities are undertaken. It was also concerned with how introducing such technology into households might shift gendered roles, not only between spouses but also among children and adolescents in the household. Shifts in agricultural roles were reported in about one-third of participating households, while shifts in decision-making regarding financial decisions were reported more widely.

Change in Roles

Approximately 20% of male producers and 30% of female producers reported that household responsibilities for producing AIVs had changed since introducing the AgUnity blockchain-based app into their respective production. At baseline, decision-making regarding the vegetables or phone management was not reported as a defined household role. Of the female farmers that reported a change in roles, 27% said they now had more decision-making regarding the vegetables and 54% said they had control over phone management (Figure 33) that they didn't have before.

Reasons for a change in roles for female farmers:

- "*I saw the value in AIV production and marketing*."
- "*Since I got training from the AgUnity group, I find it easy raising indigenous vegetables hence it takes me a shorter time to complete the farm work and do my side chores. Thus, I engage in so many more roles than before.*"
- *"Nowadays, it's easy to sell online unlike before where I had to search for customers manually, so roles had to change."*
- *"This training has helped me know what it takes to produce vegetables."*
- *"Impressed with income."*

Reasons for a change in roles from male farmers:

- *"They change with weather conditions."*
- *"Kids are in school."*
- *"I have solely undertaken vegetable farming."*

Household roles for other members of participating families also changed. For example, the responsibilities of adolescent children were reduced for all activities except marketing, while the responsibilities of young girls and boys were significantly reduced for preparing the field, planting, irrigating and bundling, cleaning, and packaging. Young boys' participation in harvesting was reduced while young girls' participation remained unchanged.

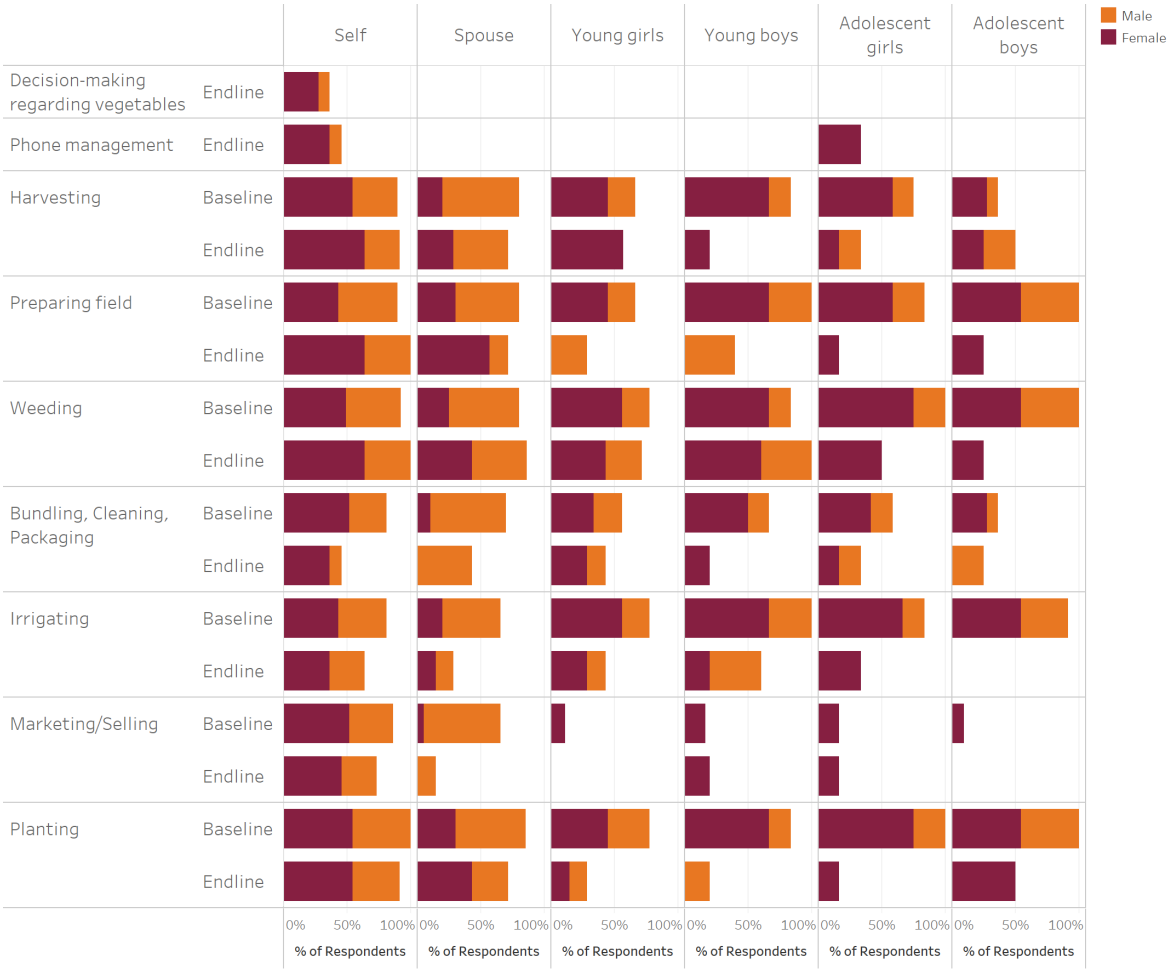


Figure 33. Change in gender roles of AIV production

There was also a shift in gender roles as it pertained to money and financial decision-making in the household between baseline and endline (Figure 34). For female producers, there was a 5% reduction in the households where financial decisions are made by someone else. Among male producers, there was almost a 20% reduction in making bigger decisions on their own without the input of a spouse. Also, among female producers, there was a 15% increase in the ability to make day-to-day decisions even if their spouse disagreed; however, this increased for men as well by 35%. For female traders and retailers, sole decision-making ability decreased significantly over the study period.

Table 18. Changes in household financial decision making

		Producer				Trader				Retailer	
		Female		Male		Female		Male		Female	
		Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline	Baseline	Endline
Who is responsible for making bigger financial decisions?	I make these decisions on my own	40%	40%	71%	53%	80%	57%		100%	80%	29%
	I make these decisions with someone else	50%	55%	29%	47%	20%	14%	100%		20%	71%
	Someone else makes decision	10%	5%				29%				
To what extent are you able to participate in day-to-day decisions?	To a high extent - You can make the decision even if your spouse/other decision maker disagrees	15%	30%	47%	82%	40%	43%		100%	50%	29%
	Medium extent - You can discuss and come to an agreement about a decision	75%	65%	53%	18%	20%	57%	100%		50%	57%
	Small extent - You can give your opinion but it is not considered in the final decision	5%	5%			20%					14%
	Not at all - You are not interested in the decision or you are not asked for your opinion	5%				20%					
Who is responsible for making day-to-day decisions about money in your household?	I make these decisions on my own	40%	45%	53%	65%	80%	57%		100%	60%	29%
	I make these decisions with someone else	55%	55%	47%	35%	20%	43%	100%		40%	57%
	Someone else makes the decisions	5%									14%

Gender Risks

Only 15% of female producers and 12% of male producers indicated that at the time of the baseline they faced gender-based risks. For women, these risks included physical risks in transporting goods to market, having many people to support, and a lack of timely payment for products. For men, risks included the challenges of having many people relying on them for support and being responsible for understanding and predicting the weather. By the endline, only 5% of male and female producers reported gender-based risks. Men did not respond to the follow-up question on what these risks were, but the female producers indicated these risks were because of the exploitative behavior of their spouses who gained financially from the increased value of their vegetable production, even though women do all the work.

Youth Engagement

Only two participants in this study were under the age of 30.[11] One unanticipated constraint of engaging youth as the primary beneficiary in this study was that since all value chain actors must be already connected, finding youth engaged in farming was extremely difficult. As a result, we were not able to engage as many youths in the project as we anticipated. However, there were two important findings we did observe through the ERT processes. The first was that because the project used smartphones and technology, youth that became aware of the project started to become engaged with the phone users even though they were not direct beneficiaries. The second was that there are numerous opportunities to engage youth in ICT-based projects beyond agricultural production alone.

Youth Engagement through Farmer Groups

As discussed further in the next section, one of the direct outcomes of this project was producers organizing themselves into farmer groups to create support in learning how to use the technology, marketing their AIVs, creating village savings and loans mechanisms, and pursuing training to increase their production of Grade A vegetables. These farmer groups attracted youth to the project. In addition to being interested in joining the AgUnity network, youth assisted the older beneficiaries of the project in learning how to use the phone. In some instances, as pictured to the right, youth assisted their parents in receiving trainings and understanding how to use the phone.

Figure 34. Participants with a youth from the community who assisted during training

Complementary Services and Opportunity Development to Engage in Agriculture

Youth in agriculture must also consider sectors other than agricultural production through which youth can be engaged. These opportunities must be interesting to students and align with their career aspirations and quality of life goals. This project created two avenues other than the direct AIV value chain to encourage youth participation in agriculture – research and tech development.

Research team

A team of 10 Egerton University fourth-year students and 2 master's students from the agricultural faculty, most of whom were agribusiness or agricultural economics students, assisted in the

[11] USAID defines a 'youth' as any one 29 years of age or younger.

formation of data instruments, data collection, and data verification at every stage of this study. Drawing on students' expertise and contextual knowledge of communities and ways of life in the study greatly enhanced the quality of the study design and implementation. Such opportunities also provide students access to global networks and provide important real-world experience that assists in accessing the job market upon graduation.

Ideathon & Hackathon

In November 2021, AgUnity in collaboration with Egerton University and supported by Virginia Tech hosted a two-week *ideathon* and 3-day *hackathon* at the university's Njoro campus. Forty-two students formed interdisciplinary teams of 5-6 individuals from the agricultural and computer science faculties. The purpose of the event was to further expose youth to the ethos of the LASER PULSE project, to *deliver practical, research-driven solutions to global development challenges*. Students were briefed on the outcomes from the initial value chain analysis and other challenges that producers and AIV actors shared with the research team that had not yet been addressed through the AgUnity V3 SuperApp.

The *Ideathon* consisted of several synchronous trainings for students on the outcomes of Phases I and II of the research on AIV value chains and employing blockchain technology to address market inefficiencies. It also trained students on human-centered design, the user experience, gender considerations in tech development, and the protection of intellectual property. Each team was required to complete the *Ideathon Workbook* before they could participate in the hackathon. This workbook asked students to think about the value proposition of the applet they would code for the AgUnity Super App environment, how they would address the pain points of their target users, map the user's journey, and create the task, wire, and user flows. AgUnity developers then met with students to discuss their workbooks and proposed an applet to simplify and strengthen their ideas so they would be prepared for the hackathon.

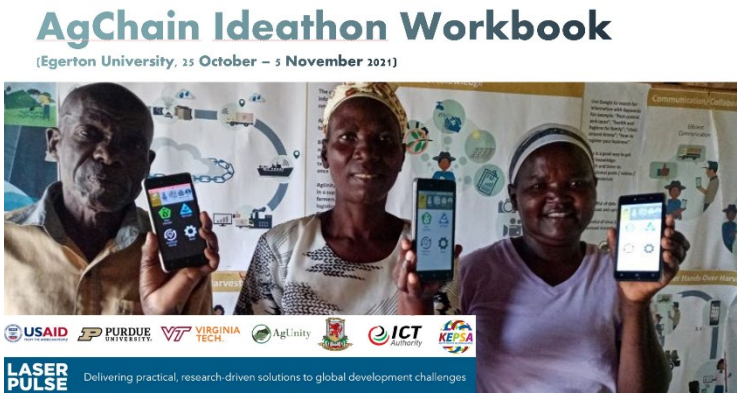


Figure 35. Ideathon workbook image

The *hackathon* took place over 3 days. Computer science students were responsible for coding the applets. AgUnity provided mentorship to the computer science students on how to code for the AgUnity environment. The hackathon concluded with students providing a pitch on their respective applets. The final applets developed were:

- **AgFinders** – connects value chain actors to improve the marketing of their vegetables by providing the location of other value chain actors to connect with.

- **Agribook** – records the transactions and expenditures of farmers to help improve financial management.
- **AgForum** – creates an online forum for farmers and experts to share solutions to production challenges.
- **AgGenius** – helps farmers find solutions to the challenges they face.
- **My Wiki** – provides an offline Wikipedia of information for farmers on how to improve their production of indigenous vegetables.
- **AgFuture** – provides an e-commerce applet for marketing vegetables online.
- **DuduFree** – provides information to farmers on how to manage pests and diseases.

Applets were judged by a panel of experts based on: how well the students communicated the challenge they were addressing with their applet; if the applet addressed that problem effectively; the functionality and usability of the applet; the visual appeal of the user interface; the complexity of the code required to create the applet; and the ability of the team to address the challenges they faced during the design and coding process. The first-place prize was awarded to AgFuture, second place was awarded to AgFinders, and third place was awarded to My Wiki. The first-place prize consisted of $500 and ongoing mentoring from AgUnity to deploy the applet permanently in their environment. The second-place prize consisted of $300 and the third-place prize was $150. All students were able to enter their app idea into the Kenya ICT Authority Whitebox program, which provides incubation for youth with app concepts to get them ready to take to market.

Figure 36. Egerton student participants in the hackathon

Other Findings

This study produced rich findings on AIV production and marketing, the impact of introducing technology into an otherwise informal value chain, and research and development opportunities for AgUnity beyond our original six hypotheses.

AIV Production and Marketing

While the AgUnity BCT-based app helped address some of the pressing challenges in AIV value chains, particularly in terms of the nature of transactions between value chain actors, producers still need considerable production assistance for them to capture the potential economic benefits of producing highly nutritious crops like AIVs. In particular, AIV production is affected by pests, disease, and drought. These issues in turn affect the income-earning potential, consistency of supply, and prices in the market.

Producers frequently cited the need for production assistance. For example, one producer stated that "*we need to be supported with weighing scales, equipment, fertilizer, wheelbarrows, and a water and irrigation system so we have reliable production*." There are also challenges in accessing high-quality inputs such as seeds and organic fertilizers and biological control for pests and disease. However, some of the participating producers have already taken the initiative to use skills, knowledge, and additional income gained from participating in this project to start investing in their production. For example, a member of the CBO shared that they "*are looking for training on grading and integrated pest management*." Others shared that through forming a legally registered self-help group, they were able to open a joint bank account and start a savings and loan scheme that allows producers to invest in new equipment such as irrigation equipment or better-quality seeds.

Continuing to expand value chain actors participating in the AgUnity BCT network will increase the income-earning opportunities for producers in growing Grade A vegetables. One producer emphasized the importance of this since currently, "*other buyers do not necessarily know about grading, and so we cannot sell as we cannot reduce the price*." Other producers echoed this sentiment. One stated, "*it is challenging when producers are many but there is only one trader*," while another said, "*we need to onboard more traders and retailers, so vegetables are always bought*."

Retailers still need assistance in marketing AIVs, particularly on the nutritional value and the organic quality of the vegetables. One retailer stated, "*we need still to be supported to promote better the knowledge about AIV, its nutrition and the organic process. Umbrellas or tents help* [in attracting attention], *especially in open markets*." Retailers also felt that other materials branded with the AgUnity name, or something related to vegetables would also assist in marketing. They suggested aprons or t-shirts as examples. As previously discussed, the increase in consumer knowledge regarding the nutritional quality of indigenous vegetables did not occur through the retailers.

However, even among value chain actors, there is a recognition of the improved quality of the AIVs that is driving increased consumption. One participant shared, "*the app makes me more aware of the quality of the AIV as the selection of goods in the app are readily differentiated between grade A and*

B." However, there is still a need to communicate the nutritional value of AIVs and how to prepare them so they retain their nutritional content. One retailer shared, "*we would like to understand better the nutritional value and how to process the AIV and to share the knowledge to our customers*."

Potential for Standardizing Transactions

Figure 37. Trader and producer negotiate prices for bundles of vegetables

The AgUnity BCT-based app and improved transactional efficiency have the potential to contribute to higher revenues from AIV sales by introducing standardization into the value chain. Prior to the study, hand bundling was the most common way for AIVs to be priced. AIVs are commonly sold from producer to trader in bundles the size of two hands (an average of 500g ± 100g) for 10 to 15 KES. These are then split by the trader who sells to the retailer in bunches roughly the size of one hand (250g ± 100g) and sold for 20 to 25 KES. Retailers then sell to consumers for roughly 20 KES per bundle of 100g ± 150g. Figure 39 the splitting process and the average price in shillings for an average of 500g of a vegetable. The producer captures only 10-15% of the final price, while the trader and retailer capture between 40 and 50%. During a marketing training session, a demonstration was given on the variability of bundle weights and the revenue that all value chain actors were missing out on (Figure 38). The participants demonstrated an emphatic consensus that standardization should be introduced into the value chain.

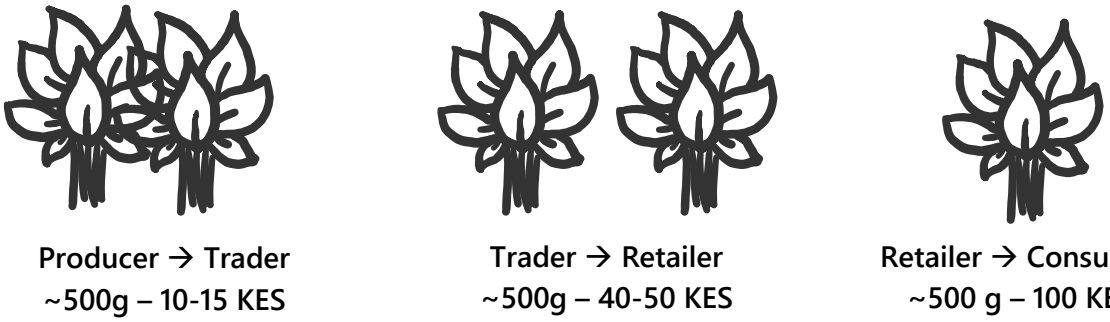


Figure 38. Price transmission along the value chain

Improved Financial Literacy

Figure 39 shows changes in the financial situation and beliefs over the 6-month study period, which shows the percentage of respondents who agreed, to various degrees, with the statement on the left. There was about a 3% reduction in the number of respondents, including men, who believed that men should have the final decision regarding household finances. There was also a 10%

reduction in the proportion of women who find it more satisfying to spend than to save. Another interesting change is the 7% reduction in both men and women who worry about paying for essential expenses.

There was a slight decrease in the proportion of the participants who have money left over at the end of the week or month. We know from the voluntary focus groups that many producers organized themselves into registered groups and started a village savings and loans scheme. However, additional follow-up is needed to understand from traders and retailers if their available cash leftover at the end of the week has increased or decreased, and, if so, why.

Of concern is the slight reduction in participants who are honest, even if it puts them at a financial disadvantage, a slight increase in the percentage of men who are unable to save due to their financial position, and the proportion of those who are paying attention to their financial affairs.

Food Traceability and Safety

AgUnity's BCT-based app introduced different grades of vegetables to value chain actors and how to keep these grades distinguishable and traceable as they move from the farm to the retailer. As mentioned previously in this report, the grading system evaluated whether or not pesticides or inorganic fertilizers were used in the AIV production process. Important next steps will be to introduce an *external* AIV grading verification and monitoring mechanism, deepen consumer trust and create transparency for consumers who may not be located so close to the area of production (i.e., urban Nairobi consumers). Participants recognize the value of introducing an external verification mechanism into the system to continue to increase consumer confidence in their product. One producer shared that "*we feel it is sensible to have the quality assurer come check our plot quarterly*." This was echoed by the other participants.

A non-BCT-related outcome of working with retailers to improve the marketability of AIVs was an increase in the recognition of the importance of food safety because of the focus on the issue in trainings related to grading. This led several retailers to improve the cleanliness of their stalls and how they presented their AIVs for sale. One retailer said, "*as retailers, we are more aware of the importance of the cleanliness of the stalls and showing the quality of our vegetables*."

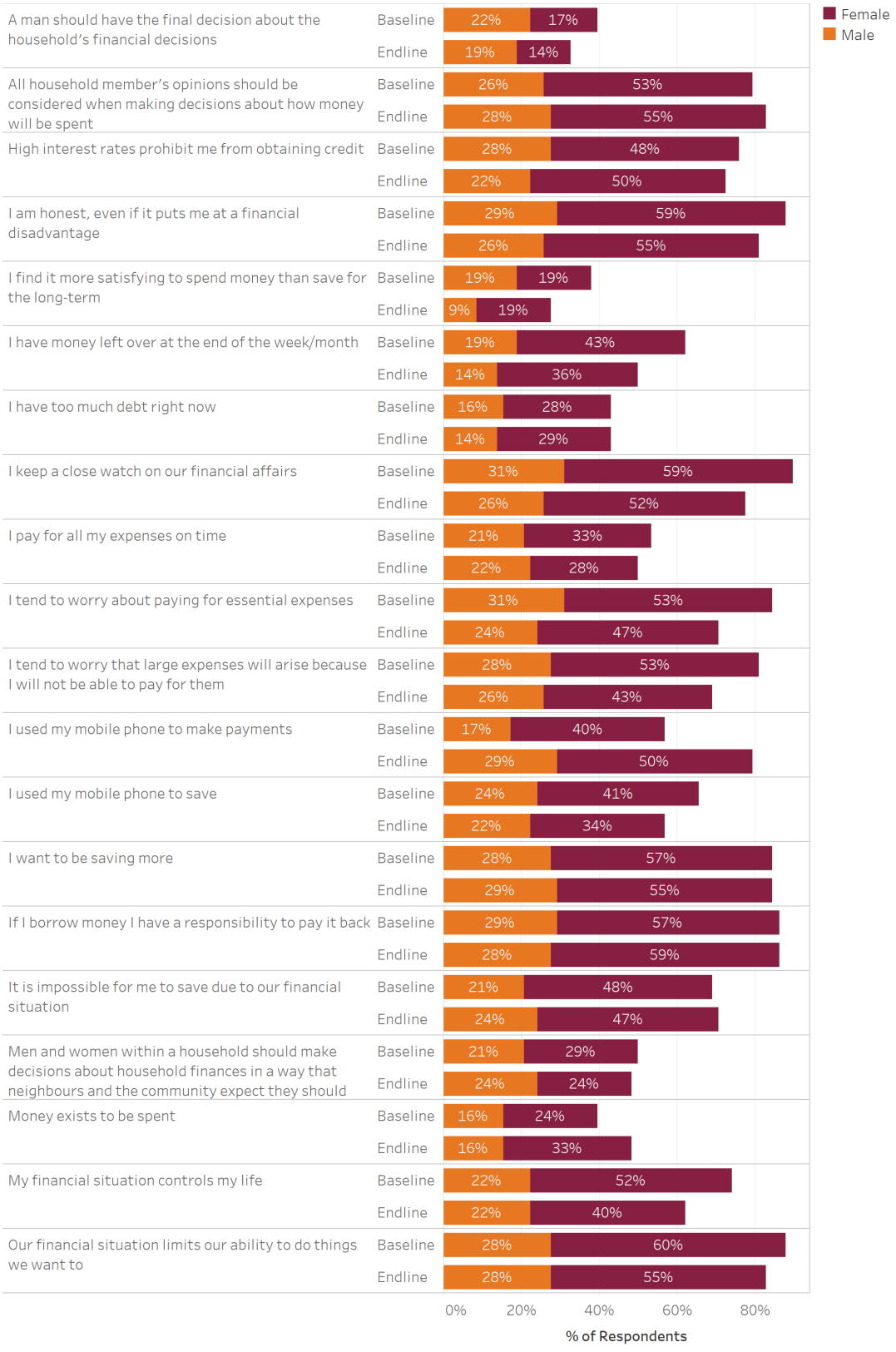


Figure 39. Changes in financial literacy by gender

Recommendations

This impact evaluation identifies the potential value that BCT can offer last-mile agricultural systems to improve value chain functionality and livelihoods. BCT cannot offer solutions for all the challenges faced by AIV value chain actors; however, there are clear linkages between the technology and food security outcomes. The following recommendations outline several areas for technology companies (i.e., AgUnity) and enthusiasts, policymakers, and practitioners that will facilitate the research and development needed to fully capture the transformative potential of BCT.

Recommendation 1. Developing low-tech traceability solutions should be a core priority for increasing demand for nutritious foods and creating economic returns for the producers of those foods.

The demand for high-quality, organic AIVs is growing in Kenya. By integrating traceability into AIV value chains, producers using traceability solutions will earn a first-mover advantage by meeting unmet consumer desires for information. This will lead to improvements in income, food security, and livelihood resilience. This evaluation reveals that conditions in the market are primed for traceability. BCT can facilitate improved transparency into otherwise opaque value chains. Tech companies like AgUnity need to consider how to make traceability functional for multiple types of consumers – i.e., those with a smartphone and those with a lower-tech phone but who still value information that will help keep her and her family safe.

Recommendation 2. Developing assistive technologies and monitoring mechanisms that minimize human interference will allow the full potential of BCT to be realized in agri-food systems.

Through the ERT process, we realized the need for developing monitoring mechanisms to provide consumers with external assurance of vegetable quality and if they were produced organically. We had initial discussions with the Ministry of Agriculture, Livestock, and Fisheries to collaborate on this monitoring and verification; however, further investment is needed to develop these systems with input from consumers to ensure that it is perceived as trustworthy. There is a need to develop assistive technologies, such as internet of things sensors or weigh scales, that will minimize human interference in the metadata of the vegetables. If these solutions can be identified, national stakeholders like the Kenya Bureau of Standards would be able to leverage BCT to scale up compliance to its standards across sectors. This in turn would develop consumer confidence in locally-produced horticulture products and facilitate access to export markets.

Recommendation 3. Community Based Organizations (CBOs) and other producer associations should be engaged to achieve network scalability and acceleration of transaction cost reduction.

The CBO *New Vision* was imperative to the success of this project. CBOs are adept at community transformation, encouraging behavior change, and harmonizing the community response. In this

case, we consider the community as the participating producers. The *New Vision* director was instrumental in coordinating activities among all participants, even those that do not belong to the *New Vision* CBO. AgUnity has worked with the director as a main point of contact to enable the field officer to easily carry out capacity-building exercises. Given the number of farmers in the CBO, it has also facilitated an easy pathway to scalability. Working with CBOs, cooperatives, and farmer/agribusiness associations going forward will help to achieve scale in blockchain-based transacting networks. This will also lead to accelerated reductions in transaction costs in the agri-food system, leading to both increased income and a lower cost of food, both of which will contribute to improved national food security.

Recommendation 4. BCT should be deployed alongside complementary digital services.

The initial value chain analysis and outcomes observed in the impact evaluation reveal that BCT alone cannot address the pain points constraining the functionality of AIV value chains. Producers, traders, and retailers need access to advisory and extension services, financial services, weather information, and markets for their produce that will continue to minimize transaction costs and ensure they are fairly compensated for their respective activities in the value chain. BCT has natural complementarities to some of these services. For example, BCT-based transaction records create a low-cost, low-risk financial history that could theoretically open up access to credit. The use of good agricultural practices or organic production could be stored on the profile of the farmer and communicated to the final consumer. One of the main findings of this project is that it is not BCT, but *BCT Plus Services* that has the most potential to alleviate the pain points of last-mile agricultural systems.

Recommendation 5. Digital solutions should not be a replacement for in-person technical training and capacity building.

The potential for digital solutions is attracting increasing investment and attention for their potential to address deeply entrenched challenges in the agri-food system. However, in-person interaction and engagement to build technical skills in producing or retailing agricultural products will continue to be invaluable. For example, while the AgUnity BCT app helped address some of the pressing challenges in AIV value chains, particularly in terms of the nature of transactions between value chain actors, producers still need considerable production assistance for them to capture the potential economic benefits of producing highly nutritious crops like AIVs. Retailers also need assistance in marketing AIVs, particularly on the nutritional value and the organic quality of the vegetables. While some of this could be offered digitally, in-person engagement to problem solve and examine the existing practices used will be essential for improving productivity sustainably.

Conclusions

This study is one of the first to explore how blockchain technology (BCT) can be used to enhance the functionality of last-mile agricultural AIV value chains in low- and middle-income countries like Kenya. It is also one of the first to investigate the potential impacts of the emerging technology on food and nutrition security. The results indicate the significant potential of BCT to improve transaction efficiency, create trust, connectivity, and coordination between value chain actors, and create better-matched markets for the highly nutritious AIVs.

The main advantage of BCT is its ability to create an immutable and secure record of transactions. Providing value chain actors with access to easily interpretable and trustworthy transaction data was found to increase the functionality of the *entire* value chain, which in turn increased the quality of the final products and the price that consumers were willing to pay for AIVs. In addition, improving the connectivity between producers and traders significantly reduced the time spent trying to coordinate the sale of AIVs. These time savings provided actors in the value chain with opportunities to engage in additional productive or social activities. While BCT did enhance relationships between those actors using the AgUnity app, trust among value chain actors who were not using the app did not change. Thus, expanding the deployment of the app to additional actors along the AIV value chain has the potential to enhance the gains already realized.

While producers accessed and leveraged the data provided by the AgUnity app, information sharing did not pick up among traders and retailers. This issue could be addressed by developing ways to share information in the app across the different groups of value chain actors – i.e., producers, traders, retailers, and consumers. Further, while the blockchain functionality did increase access to information for each user group, there was little improvement in the transfer of information from producers to consumers and consumers to producers throughout the study. This finding means the full gains from price premiums and matching supply and demand have yet to be realized.

Improving access to transaction data and introducing an AIV grading system enabled producers to focus on production practices that could generate higher incomes from Grade A vegetables. The new grading system also encouraged groups in the value chain to seek training on how to improve the quality of their AIV production. This expressed demand for training presents an opportunity for extension agents and other agricultural service providers to create programs that can provide such support. An applet containing important production information could also be developed for the AgUnity app that producers could access when needed. Given that the AIV grading system has been adopted by actors along the value chain, an important next step is to introduce an *external* verification and monitoring mechanism, to provide consumers with confidence that the vegetables they purchase meet established quality and safety standards.

The increased income from the sale of high-quality AIVs and improved production practices were found to enhance food security among study participants by increasing the consumption of vegetables and higher-quality proteins and fruits. However, the impacts were constrained since the

AgUnity app currently does not provide value chain actors and consumers with information that could improve the marketability of AIVs. This study also identified several important gendered factors that should be considered when sharing information intended to influence the purchase, preparation, and consumption of AIVs.

Finally, this study has identified a range are areas where additional research is needed to develop the transformation landscape for agriculture in Kenya and other SSA countries. First, since participants in this study were provided with a smartphone and were not asked to pay a subscription fee for the AgUnity app, an important next step will be to test different service and payment models. Study participants did express a willingness to pay a monthly fee to use the AgUnity app, but only if additional complementary services and features were offered on the app. There is also a need to enhance several existing features of the app, such as improving its daylight scanning capabilities and ensuring the app is more intuitive for traders. In addition to the AgUnity service fee, attention also needs to be given to how value chain actors will purchase smartphones that can run the app.

Second, and in relation to the above point, new applets for the AgUnity app need to be developed that provide value chain actors with access to critical information and services and provide opportunities to expand the sale of AIVs. The hackathon undertaken as part of this study presents a unique model to engage youth in the development of these applets. Expanding the services provided by the AgUnity app may also create new opportunities to reengage youth in the agricultural value chain.

Finally, future research should consider applying the AgUnity app to additional value chains, especially for those crops and products that have a direct connection to food security.

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Appendix 1 – AIV Grading Tool

AIV Grading Tool			
Criteria	**Assessment**	**Levels**	**Scores**
How will you know if inorganic pesticides or organic pesticides have been used?	• Ask the producers • Check for residues on the produce	No inorganic/organic pesticides used	3 points
		Some inorganic pesticides used	1 point
How will you know if inorganic fertilizers have been used?	• Ask producers • Signs for fertilizer containers, etc. on the farm	No inorganic/organic fertilizers used	3 points
		Some inorganic fertilizers used	1 point
Natural color (usually green for the leafy vegetables)	• Observe coloration	Natural green color	3 points
		Light green color	2 points
		Green-yellow color	1 point
Insect pest and disease injury	• Observe if free from damage	No pest/disease damage	3 points
		10-30% pest/disease damage	2 points
		Over 30% pest/disease damage	1 point
Mechanical damage/bruises	• Observe	No mechanical damage / bruises	3 points
		10-30% mechanical damage / bruises	2 points
		Over 30% mechanical damage / bruises	1 point
Freshness	• Observe	Fresh/turgid	3 points
		Partially wilted	2 points
		Wilted	1 point
Grade A - 13 points or above (≥ 70%) **Grade B - Less than 13 points (< 70%)**			