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DIGITAL SUPPLY CHAIN OPTIMIZATION AND FOOD SECURITY FOR FRESH PRODUCE IN NAIROBI COUNTY: A CASE STUDY OF KIBRA SUB-COUNTY

[1*]Ingolo Josphine Aluko and [2]Dr. Derow Aden
[1]Masters Candidate, Management University of Africa
[2]Lecturer, Management University of Africa
Corresponding Author's Email address: joeyfinah18@gmail.com

ABSTRACT
Food security is a critical challenge in Kenya, with approximately half of the population living in poverty and about 7.5 million, in extreme poverty. This is undermined by challenges in the fresh produce supply chain, such as poor market access and high food loss rates, which adversely affect nutrition outcomes. This study examines the impact of digital supply chain optimization encompassing digital logistics integration, digital market linkages, digital traceability, digital transparency and information sharing, on food security. Grounded under systems theory, the study employed a cross-sectional design. Data was collected from 319 stakeholders via questionnaires and interviews, analyzed using SPSS Version 28 for descriptive and regression statistics, and content analysis for qualitative insights. The findings indicated that digital logistics integration had the strongest positive impact through improved delivery efficiency and reduced post-harvest losses. Digital market linkages showed significant influence, **f**acilitated by mobile platforms, though adoption was constrained by low digital literacy and unreliable internet. Digital traceability systems had limited adoption due to infrastructural barriers, while digital transparency enhanced decision-making but lacked a regulatory framework**.** Analysis of qualitative insights highlighted stakeholder demand for low-technology solutions. Recommendations set out include the establishment of community Wi-Fi hubs, implementation of SMS-based tools, provision of digital literacy programs and creation of farmer cooperatives to facilitate the scaling of digital interventions. This research makes a contribution to Sustainable Development Goal 2 (Zero Hunger) and Kenya's Food and Nutrition Security Policy, highlighting strategies for urban food systems in low-resource settings.
Keywords: *Digital supply chain optimization, fresh produce, Kibra Sub-County, food security.*

INTRODUCTION
Globally, food security, as defined by the FAO, ensures consistent access to sufficient, safe, and nutritious food to meet dietary needs for an active and healthy life, yet over one billion people remain food insecure, with 2 billion facing undernutrition (FAO, 2017; WHO, 2017). In Sub-Saharan Africa, particularly Kenya, inefficiencies in food supply chains exacerbate hunger, malnutrition and micronutrient deficiencies with 29% of

children under five suffering from undernutrition and 10 million Kenyans facing chronic food insecurity (KDHS, 2020). These challenges are rooted in significant post-harvest losses (up to 40%), inadequate infrastructure, and constrained market access for smallholder farmers, who are predominant in fresh produce production (FAO, 2019). In urban slums like Kibra, where poverty and unemployment intensify nutritional food insecurity, access to affordable, nutritious fresh produce is limited, contributing to prevalence of micronutrient deficiencies and increasing incidences of non-communicable diseases (Kimani-Murage et al., 2011). Digital supply chain optimization offers transformative potential to address these issues through enhanced efficiency, transparency, and accessibility.

Digital logistics integration employs technologies like Internet of Things (IoT), blockchain, and artificial intelligence to streamline operations, reduce post-harvest losses, and ensure timely delivery of fresh produce (Kamble et al., 2019). By improving traceability and coordination, it ensures improved food safety and availability, which is critical for achieving optimal nutritional outcomes in areas like Kibra. Digital market linkages, facilitated by platforms like e-commerce and mobile apps, establish direct connections between farmers and consumers, thereby reducing intermediary reliance and stabilizing prices (Njuki et al., 2023). This fosters market transparency and affordability, addressing food access barriers. Digital traceability, using blockchain and Internet of Things (IoT), ensures food safety and quality, hence fostering consumer trust and mitigating waste (Kumar & Brint, 2019). Digital transparency and information sharing facilitate real-time data exchange, enabling better decision-making and market stability, which are vital for equitable food distribution (Perez et al., 2023).

Although Kenya's agricultural sector contributes to 26% to GDP and employs 70% of the rural population, food security remains a critical challenge in urban informal settlements of Nairobi, Kenya, despite concerted efforts by governmental and non-governmental organizations in addressing this through various programs and interventions. These initiatives have achieved limited success, particularly in areas such as Kibra Sub-County, where food insecurity affects approximately 85% of households, severely limiting access to fresh produce essential for addressing micronutrient deficiencies, stunting, and associated health challenges, exacerbating public health concerns in these communities (FAO, 2021). The reliance on informal markets, such as Toi Market, combined with systemic inefficiencies in the fresh produce supply chain, intensifies these issues, rendering nutritious food scarce, costly, and often unsafe.

The fresh produce supply chain in Kibra is hindered by significant inefficiencies, including post-harvest losses, driven by inadequate logistics infrastructure, restricted market access for smallholder farmers, limited traceability mechanisms for quality assurance, and insufficient transparency in pricing (Onwude et al., 2023). These challenges compromise the availability, accessibility, quality, and stability of nutritious

produce, critical components of food security. The low adoption of digital technologies further perpetuates these inefficiencies (Gitonga et al., 2010). A notable example is the 2018 tomato shortage in Nairobi, where urban price surges coexisted with significant produce spoilage in Uasin Gishu County, which was attributed to exploitative intermediaries and farmers' limited market access (Letting, 2018). This study therefore seeks to address these gaps by investigating how digital supply chain optimization, through digital logistics integration, digital market linkages, digital traceability, and digital transparency and information sharing can enhance food security for fresh produce in Kibra sub-county.

The primary objective of this research was to evaluate the effect of digital supply chain optimization on food security within Kenya's fresh produce sector with the specific objectives of determining the effect of digital logistics integration, assessing the effect of digital market linkages, evaluating the effect of digital traceability and determining the effect of digital transparency and information sharing on food security for fresh produce in Kibra. Optimization of digital supply chains offers critical insights for enhancing food security for fresh produce in Kenya. It will benefit smallholder farmers, policymakers, supply chain stakeholders, and researchers by developing frameworks for integrating digital tools into food supply chains. It will promote regulations that encourage transparency, data sharing, and public-private partnerships to ensure equitable access to nutritious food. The empirical evidence will also highlight the transformative potential of digitization in reducing food wastage, improving logistics efficiency, and enhancing the availability of fresh produce. The findings will moreover identify necessary investments and policy interventions to accelerate the adoption of digital technologies in Kenya's fresh produce sector, ultimately improving nutritional food security outcomes (Kiptoo & Nyambura, 2022). This study will open new interdisciplinary avenues for researchers in logistics, technology, public health, and agricultural economics, fostering further academic exploration in these fields.

LITERATURE REVIEW

Theoretical Framework

This study is anchored in systems theory (Bertalanffy, 1968), viewing the supply chain as an interdependent system where digital interventions affect efficiency and nutritional outcomes. Supporting theories include the Technology Acceptance Model (Davis, 1989), emphasizing perceived usefulness and ease of use of these digital tools, Supply Chain Management Integration Theory (Oliver, 1982), focusing on coordination between different stakeholders and processes, Resource-Based View (Barney, 1991), highlighting digital capabilities as competitive assets, and the Food Security Framework (FAO, 2006), addressing availability, access, utilization, and stability of food.

Empirical Literature Review

Digital supply chain optimization leverages technologies such as digital logistics, market linkages, traceability, and transparency to enhance efficiency, reduce food losses, and

improve access to nutritious food in Kenya. Studies have indicated that implementation of tools such as automated routing (Kamau et al., 2021), e-commerce platforms like Twiga Foods (2019), blockchain-based traceability (Kshetri, 2018), and data sharing (Wamba et al., 2020) reduce post-harvest losses, lowers logistics costs, and empower smallholder farmers by facilitating enhanced market access and price transparency. These advancements support food security pillars: availability, accessibility, and utilization (FAO, 2017) but gaps however remain in their widespread adoption and tailored application to fresh produce.

Karari (2019) posited that integration of technology into agricultural practices enhanced traceability and farmer connectivity, though specific focus on fresh produce logistics is limited. Implementation of efficient logistics systems has been demonstrated to lower transaction costs and waste while increasing stakeholder profits (Wajszczuk, 2017). Tzachor. A. (2020) demonstrated that artificial intelligence-driven demand forecasting optimizes production and distribution, reducing losses. However, inadequate cold chain infrastructure, as noted by Kitinoja (2013), contributes to significant post-harvest losses particularly of the fresh produce, underscoring the need for scalable solutions like solar-powered cold storage (Lal Basediya et al., 2013), which face low adoption rates.

Digital market linkages, including e-commerce and mobile platforms, bridge gaps between farmers and consumers, improving price transparency and market access. Hammon and Goralnik (2024) found that mobile-based linkages increase farmer incomes and consumer access to fresh produce. Adebayo et al. (2021) showed e-commerce enhances food diversity for urban consumers, while Olwande (2015) highlighted how efficient markets address smallholder challenges like high transport costs and intermediary dependence. Aker and Mbiti (2015) and Mangole (2025) noted that mobile platforms provide real-time market data, enabling better decision-making, though rural access remains limited.

Kumar and Brint (2019) highlighted blockchain and Internet of Things for tracking. Mwakio et al. (2023) reported 30% contamination reduction of produce in Kenya boosting consumer trust, but also noted low adoption of these digital tools due to costs variations persisting. Ahmed et al. (2021) showed QR code traceability increases demand for nutritious foods, but poor urban and rural consumers face access barriers due to the digital divide. Digital transparency and information sharing enhance decision-making and trust in supply chains. Nsomba (2022) found that real-time market data improved farmer incomes and food security. Milner and Hammond (2022) linked transparent markets to better dietary diversity, while Ahmed et al. (2022) noted reduced price volatility in transparent systems. Tadesse and Bahiigwa (2015) showed that digital tools reduce reliance on intermediaries, addressing information asymmetry and improving market access for rural producers.

Despite the many insights highlighted, there are still significant research gaps. Many studies conducted focus on the general benefits of digital technologies but lack specificity with regard to the impact of digital technologies on food security for fresh produce (Owuor, 2017). There is limited exploration of barriers to scaling digital tools, such as infrastructure deficits and low digital literacy (Abate et al., 2023). Cold chain logistics and traceability studies often overlook digital integration and instead, concentrates on conventional systems (Lipwop & Achuora, 2021). Additionally, few studies address Kibra-specific challenges, where informal markets and urban poverty exacerbate food insecurity (Abdulla, 2011). This study aims to address these gaps by evaluating the effectiveness of digital logistics integration, market linkages, traceability, and transparency and information sharing in enhancing food security for fresh produce in Kibra, offering actionable solutions to overcome adoption barriers.

CONCEPTUAL FRAMEWORK

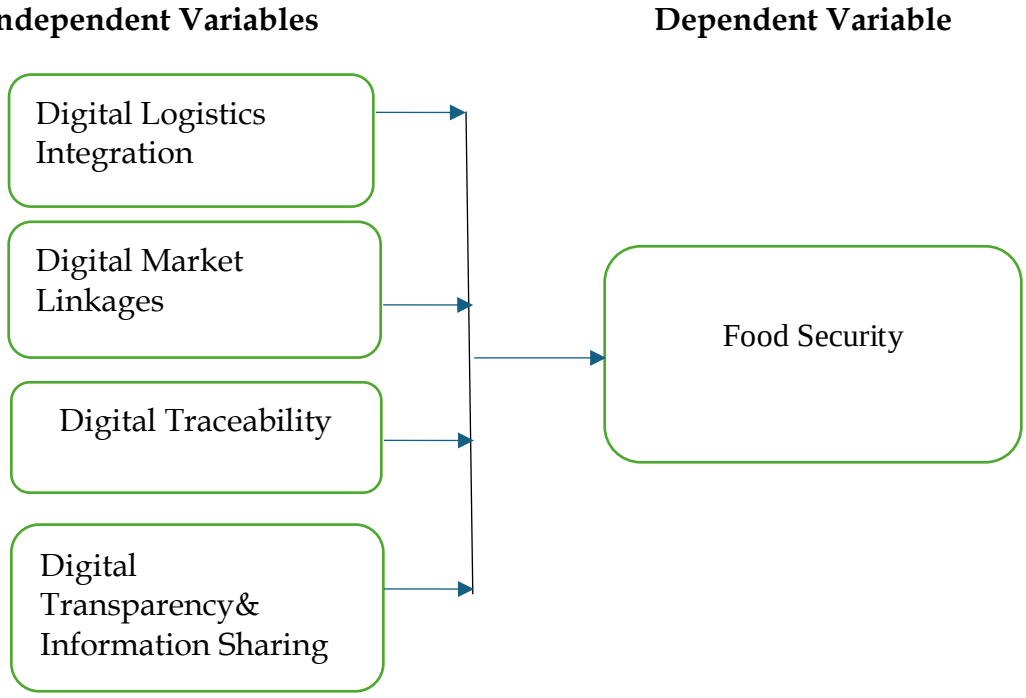

Figure 1: Conceptual Framework

METHODOLOGY

A cross-sectional research design was employed, collecting data on variables without manipulation at a single point in time, enabling efficient data gathering across diverse characteristics (Shields & Rangarajan, 2013). This design facilitated both qualitative and quantitative analysis, examining companies like Twiga Foods, Wasoko, and Taimba that utilize digital technologies to optimize supply chains. The target population comprised 185,340 stakeholders (KDHS, 2020) in Kibra's fresh produce supply chain, including end consumers, market vendors, farmers, logistics providers, digital platform providers, and

policy entities. These groups were selected to evaluate the impact of digital interventions on food security for fresh produce.

A sample size of 398 respondents was determined using the formula by Lewis (2009):

$$n = \frac{N}{1+N(e)^2}$$

where N is the population (185,340), e is the margin of error (0.05), and n is the sample size, yielding 398 participants. Stratified random sampling ensured proportionate representation across heterogeneous stakeholder groups, with purposive sampling being applied to select key informants like policymakers and digital platform providers based on expertise (Fischer, 2016). Simple random sampling was then used within strata to select respondents, ensuring no bias.

Primary data was collected through questionnaires with open and closed-ended questions, using a Likert scale for quantitative responses and open-ended questions for qualitative elaboration (Creswell, 2013). Interviews with digital platform providers, logistics providers, and policymakers explored barriers to digital tool adoption. Secondary data was gathered from published reports, journals, and industry publications via document analysis. A pilot study with 40 proportionally selected stakeholders tested the reliability and validity of questionnaires and interview guides, with feedback used to refine tools, excluded from final analysis to avoid bias. Reliability was assessed using Cronbach's Alpha, targeting a coefficient of 0.7 or higher, with items below this threshold rephrased or removed (Cooper & Schindler, 2018). Validity was ensured by aligning questions with study objectives and consulting experts in supply chain management field.

Data analysis involved qualitative content analysis to identify themes and patterns addressing research questions (Krippendorff, 2018), and quantitative analysis using SPSS for coding and statistical evaluation. Descriptive statistics (Means, SD), presented in tables and figures, summarized the data, while inferential statistics, including Pearson correlation coefficient (2-tailed, 5% significance level), assessed variable relationships. Analysis of variance (ANOVA) evaluated the model's significance, comparing computed F-statistics with a critical p-value of 0.05. A multiple linear regression model, $Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \varepsilon$ was used, where Y represented food security, X_1 (digital logistics integration), X_2 (digital market linkages), X_3 (digital transparency and information sharing), and X_4 (digital traceability) are independent variables, β_0 is the constant, β_1–β_4 measure variable sensitivity, and ε is the error term. This approach ensured a comprehensive evaluation of how digital supply chain optimization influences food security for fresh produce in Kibra.

RESULTS AND FINDINGS

Demographic Profile

Of 398 distributed questionnaires, 319 were returned yielding a response rate of 80.2%. Females dominated at 68.1%, aged mostly 25-34 at 37.7%. Majority of the population had received secondary education which was at 38.3% and was consumers heavy at 87.7%. Mobile applications were mostly used accounting for 37.6% of the population. High consumers count (87.7%) reflected on Kibra's low-income household focus. Gender and age influenced perspective on supply chain tasks (Kothari and Garg, 2015), while education affected digital adoption (Borg and Grall, 2019). On the digital technologies used for fresh produce, mobile applications and online tools dominated while blockchain and Internet of Things lagged due to literacy and internet issues, consistent with Aker and Mbiti (2015).

Descriptive Statistics

Descriptive statistics were computed for the four independent variables (digital logistics integration, digital market linkages, digital traceability, digital transparency and information sharing) and the dependent variable (food security) using a 5-point Likert scale. Higher means(M) indicated stronger agreement, and lower standard deviations (SD) suggested greater consensus. All variables scored above 3.0, reflecting positive perceptions of digital interventions, though adoption levels varied. Digital logistics integration (M=3.98, SD=1.00) involving GPS tracking, IoT-enabled cold chains, and delivery apps, were highly rated, indicating strong adoption and perceived benefits aligning with Mwakio et al (2023).

Digital market linkages (M=3.68, SD=1.04) via e-commerce and mobile payments were positively perceived but showed less consensus than logistics and reflected varied experiences due to uneven infrastructure. Digital traceability (M=3.04, SD= 1.06), using blockchain or QR codes, had the lowest scores, indicating limited adoption due to low tools awareness and ease of use, consistent with Wong L., et al (2020) on blockchain barriers and Jepkorir and Mose (2022) on IoT limitations in Kenya. Digital Transparency and information sharing (M=3.43, SD=1.03) through data sharing was moderately valued with the mean and SD suggesting moderate consensus, with regulatory gaps and trust as a constraint aligning with Budler et al., (2019) on these challenges. Food security for fresh produce was also assessed across availability, access, utilization, and stability (FAO, 2017) and with a mean of 3.36 and SD of 1.03, it indicated moderate food security with affordability as a key challenge.

Regression Analysis

Application of individual regressions showed digital logistics (R=0.65, R^2=0.423) and market linkages (R=0.62, R^2=0.384) exerted the strongest influence on food security, aligning with Kamble et al (2019) on the reduction of losses and Aker and Mbiti (2015) on the facilitation of mobile-driven access to markets, respectively. Digital transparency

(R=0.58, R^2=0.336) followed while traceability was weakest (R=0.32, R^2=0.102) due to its low adoption.

Table 1: Model Summary for Food Security

Std. Error					Change Statistics				
Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**R Square Change**	**F Change**	**df1**	**df2**	**Sig.F Change**
1	0.82	0.672	0.667	0.59	0.672	161.5	4	314	0

a. Predictors: (Constant), Digital logistics integration, digital market linkages, digital transparency and information sharing and digital Traceability

***Source**: Field data (2025)*

Effects of independent variables, digital logistics integration, digital market linkages, digital transparency and information sharing and digital traceability as the predictors, were compared and multiple linear regression used with food security as the dependent variable. The strong correlation (R= 0.820) indicates a robust relationship, with an R Square 0.672 suggesting that 67.2% of the variance in food security is explained by the predictors. The F change (161.50, p=0.000) indicates that the model effectively predicts the dependent variable.

Table 2: ANOVA[a] results for Food Security

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	225.63	4	56.41	161.5	0.000
	Residual	111.99	314	0.357		
	Total	337.62	318			

a. Dependent Variable: Food Security

b. Digital logistics integration, digital market linkages, digital transparency and information sharing and digital traceability

Food security is impacted by the independent variables as indicated by the values of 161.50. The high F value reflects the combined strength of logistics, market linkages, transparency and information sharing and traceability, though with a weaker effect, moderating the overall impact. The statistical significance of the findings is indicated by the p-value, with values of 0.000 or less than 0.05 indicating a high degree of this significance. This supports the model's predictive accuracy.

Table 3: Regression Coefficients for Food Security

Coefficients[a]					
	Unstandardized Coefficients		**Standardized Coefficients**		
Model	**B**	**Std. Error**	**Beta**	**t**	**Sig.**
Constant	0.50	0.15		3.33	0.000
Digital Logistics Integration	0.40	0.05	0.41	8.00	0.000
Digital Market Linkages	0.35	0.06	0.36	5.83	0.000
Digital Traceability	0.10	0.05	0.11	2.00	0.000
Digital Transparency and Information Sharing	0.25	0.06	0.26	4.17	0.000

It is evident that under the assumption of constant variables, there would be an increase in food security for fresh produce by 0.50. The results established the multiple linear regression model (R=0.82, R^2=0.672) which explained 67.2% of the variance, and thus demonstrated that food security for fresh produce could be expressed as a function of $Y=\beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \epsilon$. Therefore Food Security = $0.50 + 0.35X_1 + 0.10X_2 + 0.25X_3 + 0.40X_4 + 0.150$ where:

Y= Food security
β (1,2,3,4) = coefficients
X_1= digital logistics integration; X_2= digital market linkages; X_3= digital transparency and information sharing; X_4= digital traceability.

It is also evident that all the findings were of a significant nature ($p<0.001$), and were in alignment with results reported by Wanyama et al. (2023) on logistics in slums areas and on market efficiencies.

Qualitative Analysis

Content analysis of 10 interviews identified four themes ranked by coverage. Stakeholders highlighted supply chain challenges (high coverage) were being affected by post-harvest losses and intermediary exploitation, which resulted in inflated prices, digital adoption barriers (medium-high) were being affected by low literacy levels and high costs, nutritional impacts (medium) were being positively impacted by the digital tools that improved produce availability even though affordability remained low, and proposed interventions (high) were put forward which suggested ways in which access to fresh produce could be enhanced to improve nutritional food security outcomes. Stakeholders emphasized on prioritization of infrastructure needs and low-technology solutions be implemented.

CONCLUSION

Stakeholders in Kibra Sub-County strongly agreed that inefficiencies in the fresh produce supply chain, such as high post-harvest losses and intermediary exploitation, play a significant role in the prevalence of food insecurity. Respondents also strongly agreed that limited digital literacy and unreliable internet connectivity hinder the adoption of digital supply chain tools, increasing lead times and reducing access to fresh produce. Additionally, respondents agreed that low adoption of traceability systems renders the supply chain vulnerable to risks of contamination and quality concerns. Stakeholders further agreed that inadequate transparency in pricing and supply data undermines trust among farmers, traders, and consumers. Moreover, respondents noted that weak regulatory frameworks for digital platforms compromise the scalability of interventions.

Based on multiple linear regression findings, this study concludes that digital supply chain optimization practices positively impact food security for fresh produce in Kibra. Digital logistics integration and digital market linkages are the strongest predictors while digital traceability has a limited impact due to low adoption, driven by high costs and infrastructural barriers. The study also concludes that stakeholders cannot fully eliminate barriers like unreliable internet and low literacy, but they can mitigate these through targeted interventions. Mitigating these barriers requires continuous investment in infrastructure, simplified digital tools, and stakeholder training to enhance adoption and maximize nutritional outcomes. These findings align with systems theory, emphasizing interconnected digital interventions, and support Kamble et al. (2019) on the role of digital optimization in the Kenyan agriculture.

RECOMMENDATIONS

The findings reinforce systems theory (Bertalanffy, 1968) by demonstrating how interconnected digital interventions enhance supply chain efficiency and nutritional outcomes, validating the theory's emphasis on holistic system dynamics, where mitigating barriers like low traceability adoption requires integrated, adaptive approaches. Recommendations, such as SMS-based tools and literacy programs, add

theoretical value by illustrating scalable feedback loops that strengthen system resilience in low-resource urban food systems.

Practitioners in agriculture, logistics, and digital platforms can apply the findings to optimize operations. Recommendations include deploying low-tech SMS platforms for traceability and transparency, establishing farmer cooperatives for shared digital access, and conducting literacy workshops to address 30% low literacy rates, enabling practitioners like Twiga Foods and Wasoko to enhance affordability and dietary variety for low-income consumers.

The study's policy implications highlight the need for frameworks that address infrastructural barriers, with findings showing that digital optimizations can mitigate food insecurity (16% prevalence). Recommendations urge governments to invest in establishment of community Wi-Fi hubs, subsidization of low-cost digital tools, and formulation of regulations that promote transparency and data security, aligning with Kenya's Food and Nutrition Security Policy (FNSP, 2017) and Sustainable Development Goal 2. The implementation of these recommendations would foster public-private partnerships aimed at scaling the reach of interventions, thereby ensuring equitable access in informal settlements such as Kibra.

SUGGESTIONS FOR FUTURE RESEARCH

Further research should corroborate unexamined factors like climate change and gender dynamics in digital adoption, validating the current findings through longitudinal studies to assess long-term impacts beyond the cross-sectional design. Comparative analyses across Kenyan counties could identify regional variations, while mixed-methods explorations of technology as a moderator in traceability (β=0.11, p=0.046) would address scalability gaps. Additionally, investigating cost-effective traceability pilots in similar urban slums would build on the limited adoption (3.1–4.7%) observed.

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