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Tissue culture banana adoption in Kenya: Overcoming barriers through integrated policy support

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Abstract

This study examines the adoption patterns and variation across age groups of Tissue Culture Banana (TCB) technology among smallholder farmers in Meru County, Kenya, highlighting generational differences and key policy implications. The study is grounded on theoretical frameworks of adoption such as the Unified Theory of Acceptance and Use of Technology (UTAUT) and Rogers' Diffusion of Innovations, which emphasize perceived utility, facilitating conditions, and observable results. While TCB technology offers significant agronomic and economic benefits through early maturity, higher yields, and uniform growth, its adoption is predominantly concentrated among older farmers. Younger more educated farmers, show limited uptake due to multiple constraints, including high input costs, land scarcity, lack of credit access, risk aversion, and misinformation—particularly the belief that TCB is genetically modified. The findings reveal that TCB adoption and income expansion are significantly influenced by factors such as farm size, productivity, number of extension visits, household size, education level, credit access, market proximity, and perceived profitability. To bridge the adoption gap and promote inclusive agricultural growth, the study recommends a set of integrated policy actions. These include youth-targeted agribusiness incubation programs, input subsidies, tailored credit schemes, expanded extension services, improved market linkages, and awareness campaigns to counter misinformation about TCB. Additionally, supporting research and continuous monitoring will ensure adaptive, evidence-based interventions. By implementing these policy options, stakeholders can enhance TCB adoption across generational lines, positioning the crop as a sustainable, high-return, and climate-resilient option for smallholder farmers and contributing to broader rural transformation

Keywords: Adoption, banana, revenue, patterns, youth

Introduction

Food is a basic human need and a fundamental pillar of a healthy and productive society. However, in Kenya, food availability remains elusive for many citizens. The country is food-deficient and relies heavily on market supply and a predominantly rain-fed agricultural production system to meet local food demand (Wambua, Omoke, & Mutua, 2014) [29]. The major staple foods produced locally include maize, rice, wheat, Irish potatoes, and bananas.

Bananas are cultivated in Kenya for both household consumption and market sale. The average annual production exceeds 1.8 million metric tons (FAO, 2017) [9], making the crop a significant contributor to national food security. Globally, bananas provide over 25% of the daily carbohydrate intake and are cultivated in more than 150 countries (WHO, 2023) [32]. In 2017, global banana production was estimated at approximately 125 million metric tons, with India accounting for about 25% of total output (Filipenco, 2023; FAO, 2018) [7, 10]. While Asia remains the largest banana-producing region, Latin America and the Caribbean dominate global exports, contributing nearly 80% of the total (Voora, Larrea, & Bermudez, 2020) [28].

In Kenya, banana production is primarily undertaken by smallholder farmers, many of whom are women. Yields range between 4.5 and 10 tonnes per hectare (Jiménez, Mainar-Causapé, & Ferrari, 2021; Masinde *et al*., 2012) [23, 17]. The key banana-growing regions include Kisii, Vihiga, Bungoma, Kakamega, and Kericho in Western Kenya, as well as Murang'a, Embu, Nyeri, and Meru in the Central region. Despite the favorable agro-ecological conditions, banana production remains low and unable to meet growing national demand. This deficit is exacerbated by rapid population growth, urbanization, unfavorable production conditions, labor and supply chain disruptions, and both macro- and microeconomic shocks that are linked to climate change (Jiménez *et al*., 2021) [23].

To understand adoption patterns in banana farming, this study draws on three theoretical paradigms: innovation diffusion, the socioeconomic perspective, and the technology acceptance model. The innovation diffusion theory, first introduced by Ryan and Gross and later expanded by Rogers, classifies adopters into innovators, early adopters, early majority, late majority, and laggards, based on socioeconomic status, personality traits, and communication behaviors (Ruzzante, Labarta, & Bilton, 2021) [30]. While widely used, this theory has been critiqued for assuming the universal appropriateness of innovations, regardless of context (Ruzzante *et al*., 2021) [30].

The socioeconomic perspective focuses on utility maximization and risk aversion within the framework of unequal access to resources. It emphasizes that farmers

make adoption decisions based on economic constraints, resource endowments, and risk considerations. This perspective is particularly useful in understanding why resource-constrained smallholders are often hesitant to adopt input-intensive technologies such as tissue culture bananas.

The technology acceptance model complements these perspectives by stressing the importance of perceived usefulness and ease of use in influencing technology uptake. Farmers are more likely to adopt innovations when they believe the technology will enhance productivity and is compatible with their farming systems.

Banana remains a critical crop in Kenya's food security strategy, yet its production potential is underutilized. Understanding the multidimensional drivers and barriers to technology adoption can inform more effective agricultural policy. Addressing structural constraints such as land fragmentation, limited market access, and poor infrastructure—while promoting access to credit and technical support, particularly among youth—will be essential for improving banana productivity and overall farmer welfare.

Finally, the individual adopter-perception paradigm captures the subjective attributes of innovations that influence adoption behavior. Together, the three paradigms determine the ultimate adoption patterns among individual farmers.

Increased adoption of tissue culture banana (TCB) production holds significant potential as a game-changer for enhancing household food security and access (Wossen *et al*., 2017) [33]. These perspectives also offer pathways to higher incomes and contribute to diversifying diets away from traditional staple foods, whose production remains low and insufficient to meet local demand. However, adoption rates of TCB in Kenya remain relatively low compared to neighboring countries such as Uganda and Burundi (Wossen *et al*., 2017; Warinda *et al*., 2020) [33, 8].

New technologies often present hurdles to adoption, either through specific constraints or prerequisite conditions. Constraints may include farm-level factors such as limited financial capital, labor shortages, or low soil fertility. Prerequisites, on the other hand, refer to broader institutional, economic, or social conditions that must be in place to facilitate adoption. If these prerequisite conditions, are not met, even a rational farmer may choose not to adopt the new technology (Wossen, Berger, & Di Falco, 2015) [34]. The conditions include among others the availability of quality inputs and the presence of functional markets,

Some adoption studies have examined these prerequisite conditions at the individual level, focusing on factors such as awareness of the technology (i.e., non-exposure bias), access to inputs, and access to credit. This presents the central puzzle that motivated the current study: to identify the strategies that would effectively enhance the adoption and production of tissue culture bananas in Kenya.

Methodology

Adoption studies typically use correlation analysis to explain adoption behavior as a function of various factors gathered through farmer surveys. In other words, they aim to estimate an adoption function of the form:

$$Adoption = f(X_i) \quad \text{where } X_i \text{ are the predictor variables, } i = 1,2....,n \quad \ldots\ldots(1)$$

Where X is a matrix of socioeconomic, personality, environmental, farm financial, farm management, or external factors, which are gathered through surveys.

The studies assume that farmers are rational actors who aim to maximize an unobserved expected utility function. Variables may influence expected utility either directly or indirectly leading to variable yields, which makes the potential revenues variable due to adopting improved technology.

$$\begin{aligned} &Max E(U) \\ &st \\ &a_{ij} x_i \le b_i \end{aligned} \quad \ldots\ldots(2)$$

Revenues is thus be used as a proxy for expected utility following adoption of TCB given existing resource constraints. The choice variables can influence influence the expected utility indirectly, through a relationship with risk. For example, education may reduce risk-aversion, and thus encourage more educated farmers to adopt innovations, which promise higher incomes but less security.

Adoption can thus be expressed as

$$y = \begin{cases} 1 & when \quad x \ge 0 \\ 0 & otherwise \end{cases} \quad \ldots\ldots(3)$$

There is a general belief that technologies being fronted as modern are better than what is existing. This fallacy needs to be discounted before any adoption process takes place. The effectiveness of a technology is realizing better performance depends on resource availability and suitable environment. Since farmers aim to maximize utility by choosing not to adopt, choosing to delay adoption, or choosing to partially adopt technologies based on their risk averseness.

Results and Discussion

Patterns of Adoption

The most commonly grown banana variety in Meru is Keganda, which accounts for 46% of the total production, followed by Kampala at 13%. The average annual yield per farm was 353 kg, with an average farm size of 1.7 acres. This translates to a yield of approximately 207 kg per acre. The level of adoption of tissue culture banana (TCB) among the sample drawn from Meru was about 3%. This is in sharp contrast to earlier studies, which reported adoption rates of between 62% and 70% for new technologies when they were first introduced in the early 1990s (Thuo, Nguluu, & Kisangui, 2017; Masinde, Obare, Owuor, & Wasilwa, 2013; Omari, Muna, & Mburu, 2024) [26, 17, 6]. Notably, although almost all farmers had banana crops on their farms, only a meagre 1% were cultivating TCB (see Table 1 below).

Table 1: Banana Adoption and Cultivation Characteristics in Meru County

Characteristic	Category	Percentage (%)
Banana Variety Grown	Keganda	46.0
	Kampala	13.0
	Other Varieties	41.0
Tissue Culture Banana (TCB) Adoption	Farmers growing bananas	~100.0
	Farmers growing TCB	1.0
	TCB adoption rate (sample)	3.0
Years of Banana Farming Experience	More than 10 years	62.0
	Less than 10 years	38.0
Farmer Age Distribution	Above 60 years	Declining adoption
	Under 35 years	<4.0
Farm and Yield Characteristics	Average farm size (acres)	1.7
	Average annual banana yield (kg)	353
	Yield per acre (kg)	~207

Notes

1. Yield per acre is derived from the average yield (353 kg) over an average landholding of 1.7 acres.
2. The observed decline in TCB adoption contrasts with historical uptake rates of 62-70% in the 1990s.
3. Less than 4% of banana farmers in the sample were youth (under 35), indicating a potential generational gap in adoption.

For business-oriented farmers, this trend is particularly troubling, as it signals a decline in the adoption of Tissue Culture Banana (TCB) farming, with only a few new farmers embracing the technology. The older generation shows a higher adoption rate compared to the younger generation. Notably, 62% of respondents had more than 10 years of experience in banana farming, indicating long-term engagement with TCB. However, the adoption rate declines significantly among farmers aged over 60. Younger farmers—particularly those under 35—represented less than 4% of the sample. The majority of current TCB farmers adopted the technology in the 1990s and have continued its cultivation since then. These findings suggest that willingness to adopt TCB increases with age up to a certain point, after which it declines.

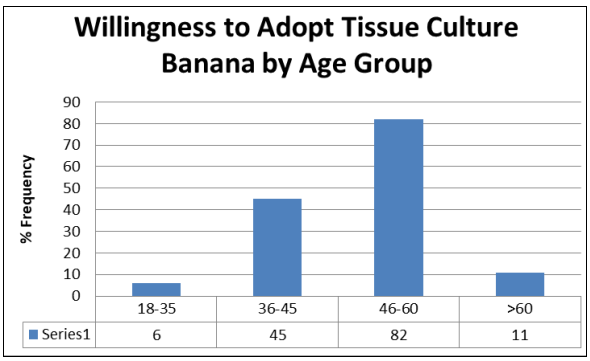

Fig 1: Farmers' response to the adoption of TCB technology.

The initial wave of TCB adopters embraced the technology at a time when returns from small-scale agriculture could adequately support household needs under a less diversified production system. However, as population pressures on land have increased, the viability of growing long-maturing crops like TCB has decreased—especially in the absence of alternative livelihoods (Otieno, 2024) [4]. The current youths desire faster and higher means of getting incomes to sustain modern lifestyles. They had no time for ventures that take time to realize returns slowly. While earlier studies found that the desire for higher revenue was a key driver of adoption in the 1990s, this motivation appears less influential today.

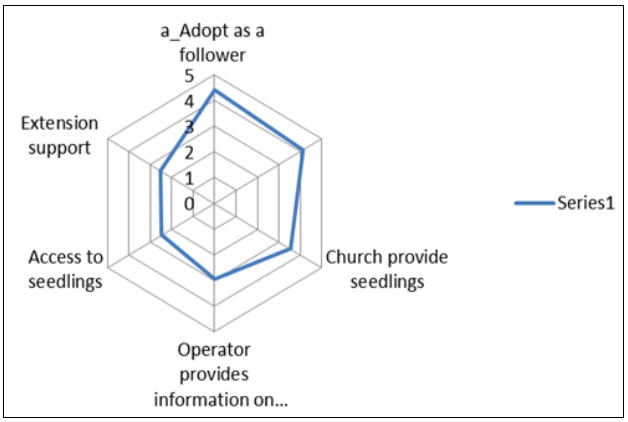

Fig 2: Conditional input requirement response for adoption of TCB in Meru.

Facilitating conditions such good results from early adopter sand receive financial support to grow TCB. The younger generation did not eke enough returns for a living from alternative business business ventures where the also lacked skills (Otieno 2024) [4]. This deepened their misery and majority barely eke a living from those investment. Figure 2 shows that current adoption is characterized by a "wait and see" approach where the youth are willing to adopt new TCB technology only when it guarantees higher output and revenues. Pressure on land also denied the youth a major farming asset. The current generation has a high demand for higher incomes to meet the contemporary lifestyles and would thus engage in highly productive ventures that mature early. While most studies reported that the desire to earn higher revenues drove technology adoption agenda in the the early 1990s, that same does not hold now.

The adoption patterns among younger farmers revealed a generally risk-averse approach. Previous studies showed that adoption was conditional on access to extension support, financial assistance, and information from seed operators and even faith-based organizations (FBOs) conditions that are now less financially viable.

According to the Unified Theory of Acceptance and Use of Technology (UTAUT), technology adoption is driven by

expected performance. However, the reluctance younger farmers' to adopt TCB contradicts this theory, even with public and private sector support in place (Otieno and Mose, 2025) [5]. The United Theory of Acceptance and Use of Technology is well aligned with the Chi-square results showing that adoption of new technology has a strong relation with extension service providers, financial assistance and information sources.

Considering the descriptive data Table 1, adoption patterns is influenced by education level. Majority of TCB farmers have primary and secondary level education yet those willing to adopt are the younger generation who account for a large percentage of willing adopters. While the younger population that is more more educated is largely non-committal about adoption. This suggests a conditional willingness to adopt, hampered by barriers such as high input requirements, seed costs, and lack of credit access.

Importantly, farmers perception influence the adoption patterns. Approximately 65% of respondents believed TCB to be genetically modified (GMO), perceiving it as a potential threat to human health. This misconception has contributed significantly to the low adoption rates. On whether TCB affects the cultural production practice, the farmers did not have conclusive decision as they all agree to some extent. Equally, lack of credible information about TCB hinders adoption.

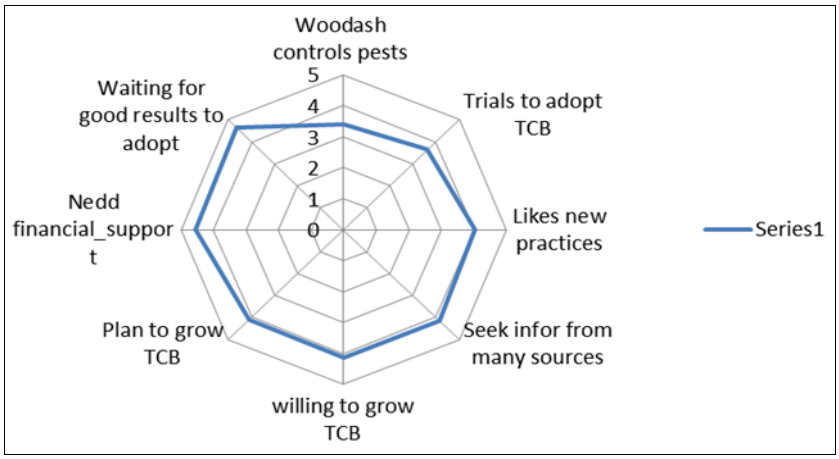

Fig 3: Farmers conditional demand to grow TCB

These observation are part and parcel of Rogers's Innovation Diffusion Theory, the Concerns-Based Adoption Model and the Technology Acceptance Model, and the United Theory of Acceptance and Use of Technology (Otieno and Mose, 2025) [5]. These theories expound that farmers will only adopt new technologies based on their utilities. Where farmers, adoption of new technology Omari *et al*, (2024) [6] found out that bout above 62.2% for both adopters and non-adopter of farmers desired to adopt tissue culture banana. This high preference was dependent among others on high average yield reported for TCB whose productivity was about ten tons of fruit per acre compared to five tons by native bananas. This supports the hypothesis that the adoption of agricultural innovations follows predictable patterns rooted in these established theories (Otieno and Mose, 2025) [5]. Therefore aligning tissue culture technologies interventions for improved food access with social, individuals construct and their malleable perceptions can enhance adoption and food access outcomes.

Correlation between the variables

A correlation was established between the variables that were to be included in the regression. These variables addressed the risk factors that farmers face, market risk, labour risk, information risk, financial risk, production risk, health risk and group dynamics.

Table 2: Correlation coefficient among determinants of adoption

obs=22)

	MKTDIST	FIELDM~B	GMOSAF~Y	NEEDFI~E	Educa	HHSIZE	FARMSIZE	VAR00095	FASSOC~N	NOEXTV~T
MKTDIST	1.0000									
FIELDMNTCB	0.1968	1.0000								
GMOSAFETY	0.0302	-0.3545	1.0000							
NEEDFINACCE	0.1163	-0.1816	-0.2390	1.0000						
Educa	-0.3337	-0.2125	0.3712	-0.3858	1.0000					
HHSIZE	0.4235	0.1335	0.4252	-0.2134	0.1729	1.0000				
FARMSIZE	0.6826	0.0271	0.1017	0.0630	-0.1749	0.4530	1.0000			
VAR00095	0.1340	-0.3001	0.2666	0.0654	-0.0044	0.2160	0.6337	1.0000		
FASSOCITION	-0.1958	0.0612	0.1693	0.0867	0.1873	-0.0185	-0.1926	-0.0909	1.0000	
NOEXTVISIT	0.4532	0.0899	-0.2722	0.2829	-0.3552	0.1389	0.2155	-0.1508	-0.2318	1.0000

Using the United Theory of Acceptance and Use of Technology (ATUT), these variables were regressed on farm level income which determined to a large extent whether farmers would benefit from adoption. The results are presented in Table 2 below. The data fits the model quite well with a high adjusted-R^2 of 0.88. This implies that the appropriate variables were used in the analysis.

Table 3 presents an analysis of the key factors influencing income expansion. These include productivity, number of extension visit, farm size and household sizes. The data show that productivity, number of extension visits, farm size, and household size have a significant and positive effect on household income growth.

Table 3: Determinants of adoption of TCB in Meru

```
. regress LNincome Educa  HHSIZE FARMSIZE  VAR00095  FASSOCITION  NOEXTVISIT MULTSOUINFO  FIELDMNTCB MKTDIST GMOSAFETY NEEDFINACCE
note: NEEDFINACCE omitted because of collinearity

      Source |       SS           df       MS      Number of obs   =        22
-------------+----------------------------------   F(10, 11)       =     17.05
       Model |  8.44466528        10  .844466528   Prob > F        =    0.0000
    Residual |  .544776898        11  .049525173   R-squared       =    0.9394
-------------+----------------------------------   Adj R-squared   =    0.8843
       Total |  8.98944218        21  .428068675   Root MSE        =    .22254

------------------------------------------------------------------------------
    LNincome |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       Educa |   .2145667   .1195737     1.79   0.100    -.0486133    .4777467
      HHSIZE |  -.1617724   .0688019    -2.35   0.038    -.3132045   -.0103403
    FARMSIZE |   .4071522   .0932965     4.36   0.001     .2018079    .6124965
   VAR00095  |   .0002783   .0000706     3.94   0.002     .0001229    .0004337
  FASSOCITION |  -.3112369   .1546016    -2.01   0.069    -.6515128     .029039
  NOEXTVISIT |   .0343009   .0439336     0.78   0.451    -.0623964    .1309981
  MULTSOUINFO |   -.341674   .0941291    -3.63   0.004    -.5488507   -.1344972
  FIELDMNTCB |   .2138978   .1278881     1.67   0.123     -.067582    .4953776
     MKTDIST |  -.1660601   .0346975    -4.79   0.001    -.2424287   -.0896915
   GMOSAFETY |  -.0334296   .1369513    -0.24   0.812    -.3348574    .2679982
  NEEDFINACCE |          0  (omitted)
       _cons |   12.05712    .384648    31.35   0.000     11.21052    12.90373
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```

These variables are not only directly associated with higher productivity but also with enhanced engagement in agricultural markets (Otieno and Mose, 2025 and Haile *et al*; 2022). [5, 16] Increased market participation, a critical component for income generation, was further influenced by factors such as education level, farming experience, banana yield, market access, amount of credit received, and farmers' perception of market prices. These findings are consistent with previous studies (Otieno & Mose, 2025; Haile *et al*., 2022) [5, 16], which emphasized the role of socioeconomic and market-related factors in shaping farmers' decisions to commercialize their production. Regarding adoption the study further reveals that high TCB yields confers a positive attribute to increased adoption of the TCB technology translating to better returns hence meeting the objective of the small scale farmers. In addition, the theories defined the apriori sign of the endogenous variables. Farm size, productivity and market distance had strong positive correlation and can thus be used a proxy for each other. However, market distance had a negative impact on farm incomes since cost of services and inputs increase with distance. This reduces the potential total returns.

The characteristics of TCB banana that lead to increased adoption is the high yield characterized by early maturing, high bunch weight, and uniform development and growth characteristics. TCB banana matures in 300 days unlike the other traditional varieties which take 400 days (Omari, *et al*, 2024) [6]. The net effect is higher returns on investment with a shorter payback period. As such, TCB venture is a suitable business venture for small holder farmers since it does not lock seed capital for long.

The growth characteristics also makes it easier for farmers to control field practices, enabling simultaneous harvesting, planning and operate an efficient TCB marketing activates. corroborated these results and reported that the desire of local farmers to adopt a new technology is influenced by high production that must meet their consumption needs with the surplus being marketed. The marketable surplus provides income used to cover expenditures for enhanced food access and other household requirement.

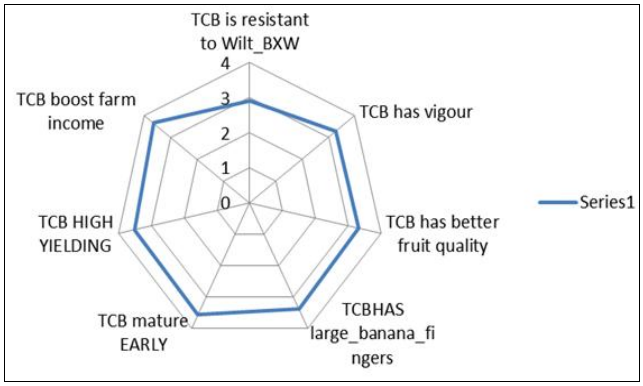

Fig 4: Traits endearing farmers to adopt TCB in MeruCounty.

Th figure shows the traits of TCB that endeared them to adopters. The most important were early maturity, high yielding and boosting incomes. With increased consumption of plantain as an alternative to the main staple foods in

Kenya, increased productivity and adoption of TCB banana promises a better future for farming households. Small sized housholds have low consumption and hence a bigger marketable surplus for sale and household income. In the local markets, TCB banana fetches three times more income than ordinary banana.

The crop has a uniform growth pattern that allows simultaneous harvesting, Further, the bundles are larger and heavier than traditional ones, which do not mature uniformly. TCB banana therefore made marketing easy and therefore supported the claim by farmers that the adoption of tissue culture banana significantly increased returns from market sales. This motivated farmers to participate in credit financing to improve their investment portfolio. Consequently, any efforts to boost household income from both agricultural and non-agricultural sources such as credit will spur the uptake of new technology, like tissue culture bananas.

Tissue culture banana technology not only transcend the benefits of the green revolution by providing high yielding genetically identical plantlets that were disease resistant (Thuo el al,2017; Masinde, *et al*, 2013, and Omari, *et al*, 2024.) [26, 17, 6], but that produce had a high market demand. Omari (2024) [6] reported that on average, 57.5% of respondents, felt that the disease resistant tissue-culture bananas have a greater demand. This consists of 60.4% of non-adopters agreed and 72.2% of adopters ((Thuo el al,2017) [26], Masinde, *et al*, 2013 [17], and Omari, *et al*, 2024) [6]. This indicates that TCB is a low cost technology and could be favoured by commercial farmers who were targeting high returns. The low cost production technology therefore incentivized increased adoption. Therefore, The combined ability of farmers to use TCB technology to realize increased yields, high returns market at a low cost are critical cognitive elements that contribute to increased farmers adoption (Ţiţan, 2015) [27].

Conclusion

The study reveals that while Tissue Culture Banana (TCB) technology holds considerable potential for increasing agricultural productivity and household income, its adoption is heavily skewed toward older generations of farmers. Younger farmers, despite being more educated, show limited engagement due to several barriers including high input costs, land scarcity, risk aversion, limited access to finance, and misinformation about TCB being genetically modified.

The findings indicate that adoption of TCB is significantly influenced by factors such as farm size, productivity, number of extension visits, household size, market access, education, credit availability, and farmers' perception of profitability. These variables are positively correlated with both increased income and market participation. TCB's agronomic benefits such as shorter maturity period, uniform growth, and higher yield making it well-suited for smallholder commercialization, especially in regions experiencing land pressure and high food demand.

The study also confirms the relevance of adoption theories such as the Unified Theory of Acceptance and Use of Technology (UTAUT) and Rogers' Diffusion of Innovations, which explain that farmers adopt technologies based on perceived utility, access to facilitating conditions, and observable results. However, the current generation of farmers demands faster economic returns and remains hesitant to invest in ventures with delayed payoffs.

Therefore, while TCB technology has a strong potential to transform banana farming in Kenya, especially in Meru County, strategic interventions are required to address the generational adoption gap and align technology diffusion efforts with evolving socio-economic realities.

Policy Options

To enhance the adoption of Tissue Culture Banana (TCB) technology and support smallholder farmers, particularly the younger generation, the following targeted policy interventions can apply. First, youth engagement in agribusiness must be strengthened through the establishment of agribusiness incubation programs that focus on quick-return technologies like TCB. These efforts should be complemented by initiatives that improve access to land for young farmers, such as subsidized leasing schemes or the formation of youth cooperatives.

Access to affordable inputs and credit also remains a critical barrier. To address this, input subsidies or starter packs containing seedlings and fertilizers should be provided to first-time adopters. In parallel, youth-friendly and accessible credit facilities integrated with TCB investment training may incentivize adoption and promote responsible financing.

Extension services and information dissemination must be expanded and improved. Scaling up both public and private extension services will ensure that farmers receive timely, credible, and technically sound guidance on TCB. Leveraging digital platforms and trusted community influencers such as progressive farmers or faith leaders can help counter misinformation—particularly the widespread misconception that TCB is genetically modified.

To foster collective action and market access, policies should support the formation and strengthening of farmer groups or cooperatives. These organizations can reduce transaction costs and improve farmers' bargaining power. Establishing direct linkages with off-takers and processors will further create reliable demand and favorable price incentives for TCB.

Sustained support for research and development is essential. Investments should be made in ongoing research to enhance TCB strains tailored to local agro-ecological conditions. Moreover, regular monitoring and evaluation of adoption trends will provide feedback loops for adaptive, evidence-based policy formulation.

Lastly, targeted communication strategies are crucial for addressing perception gaps. Public awareness campaigns should clearly explain the scientific foundation of TCB and correct GMO-related misconceptions. Sharing success stories of early adopters can inspire confidence among hesitant farmers and help shift community attitudes in favor of the technology.

By implementing these integrated policy measures, stakeholders can unlock the full potential of TCB as a high-yielding, climate-resilient, and profitable crop, making it an attractive and sustainable option for both current and future generations of farmers.

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