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REVIEW ARTICLE

Overview of the Current Status of Uganda's Banana Sector: Formalizing the Matooke Sector may not be the Best Policy Option

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Abstract:

Banana or matooke holds a matchless place in the Ugandan livelihoods. It serves as a food security crop, income source, main dish, cultural artifact, and other daily purposes. The crop is grown mainly for subsistence with little input investment, resulting in overall low productivity. Currently, the southwestern region of the country is the largest banana-producing area overtaking the central, and the geographical shifts are aligned with the gradual changes in the Ugandan society as well as the agro environments. Different from conventional thoughts, the matooke value chain does not appear to marginalize a particular group, farmers. Matooke producers maintain wide varietal diversity based on specific production goals, and improved hybrid adoption is low due to unique banana-plot replacement, cultivar diversity, and plantlet delivery systems. High adoption of biofortified matooke appears questionable because of genetic modification and other relevant issues. Overall, the matooke value chain seems to operate rather flexibly, being built on organized informality and social networks. This implies that pushing for a formalized system may not be the best policy decision for the matooke sector. Nonetheless, public interventions could be prioritized for improved matooke production and distribution by investing in extension services, grading criteria, and road/infrastructure.

Keywords: Agriculture, Banana, Food security, Matooke, Uganda, Value chain.

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1. INTRODUCTION

Uganda can be described as a rural economy since agricultural activities dominate local livelihoods and involve over 70% of the total labor force of the country [1]. Banana is a major food crop for half of the Ugandan population, and approximately 75% of the Ugandan farmers cultivate it [2, 3]. The country records the highest per capita consumption of banana in the world or 220-400 kg per annum, and the crop is estimated to provide Ugandans with up to 30% of their daily caloric intake [3 - 5]. Banana plants deliver a continuous supply of food and income through the asynchronous fruiting habit, and the crop's contribution to household food and income security is acknowledged by the Ugandan government as a prioritized crop [3, 6]. Banana plants are also integral for other daily usages; the pseudo-stems are used for animal fodder; the fibers for ropes, mats, and baskets; the leaves for mulching, packaging, and food-wrapping; some cultivars for medicinal purposes [7].

Based on its main usage as food, bananas can be categorized into five types: cooking, brewing, roasting, sweet dessert, and multi-use types [8]. Farmers in Uganda often grow multiple cultivars of those types, and the cooking type or East African Highland Banana (EAHB, *Musa spp.,* group AAA-EA) dominates the type-cultivar mixed banana stands across the country [9]. The cooking type, locally known as matooke, contributes to approximately 90% of all bananas produced in the country, and 97% of the sampled banana-producing households were found to grow at least one cooking banana variety [1, 3, 8]. Banana production in Uganda has been driven mainly by household consumption rather than commercial goals [8]. With the annual matooke production of over 6 million tons, it is estimated that 70% of it is for household consumption while 30% is for sale [3, 10]. Regarding yields, the current annual yields range from 5-30 tons per ha, which is well below the attainable yields of 60-70 tons per ha per year [9, 11]. This is partly related to that most banana including matooke in Uganda is cultivated by smallholder farmers for subsistence with little input investment [10].

The significance of matooke in the Ugandan diet can be found in that matooke connotes food prepared from EAHB as well as the crop itself [12]. Matooke, when cooked, is characterized by a unique taste, aroma, soft texture, and golden yellow color, which constitute the unique quality described as tookeness [10]. In Luganda, a language spoken in central

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Uganda, matooke signifies food more generally, resonating with the crop's deep connection to the sociocultural lives in this region [7, 12]. Additionally, the distinctive status of matooke is ironically reflected in an unsuccessful attempt by the government with the crop. The Ugandan government established the Presidential Initiative on Banana Industrial Development in 2005, under which a banana processing factory was set up to produce matooke flour and other matooke products [13]. However, the processed flour has gained little domestic market acceptance, which implies difficulties influencing how Ugandans utilize and perceive matooke [14].

Against this backdrop, the objective of this article is to examine the overall state of this singular crop's cultivation and utilization, and related issues more from the sociocultural perspectives. This review intends to provide updated insights into the crop for domestic policymakers in food security and smallholder livelihoods, and for international donors who are interested in supporting Ugandan agriculture and food production. The article is organized as follows; the second and third sections examine the overall banana cultivation and value chain, the fourth section reviews banana varietal selection and hybrid adoption, the fifth section looks at dissemination mechanisms of banana planting materials, the sixth section examines biotechnology application to this staple crop for vitamin A biofortified matooke as a case example, and the last section concludes with policy recommendations. Before proceeding, it is worth noting that the two terms (banana and matooke) are often used interchangeably as the vast majority of banana produced and consumed in Uganda is matooke.

2. BANANA CULTIVATION

Banana occupies the largest cultivated area in Uganda or 30-38% of the cropland on average 0.3-0.5 ha plot [3, 4, 10, 15]. The crop is grown mostly by resource-poor smallholders, likely mixed with other crops, and dependent on rain-fed production systems [16, 17]. A study suggests Ugandan banana producers appeared rather inefficient, and outputs could be increased up to 58% with improved technical efficiency [18]. Relatedly, the present banana yield is very low, or 5-30 tons per ha per year, compared to the attainable yield of over 60 tons per ha per year [9, 11]. Studies observe banana productivity in Uganda has been declining while regional variations may exist (Table **1**) [17]. Factors associated with declining productivity include deteriorating soil fertility, inadequate soil moisture, pests such as banana weevil and nematodes, and diseases such as Banana Xanthomonas Wilt (BXW) and Black Sigatoka [11, 17]. On top of those factors, land use changes from rapid urbanization, labor shortages, and poor agronomic practices are all associated with reduced banana productivity in the country [19].

Regarding soil nutrient deficiencies, Ugandan farmers tend to use little market-purchased fertilizer due to its cost, availability, and uncertain quality [19, 20]. A study indicates the probability of fertilizer use in bananas was strongly associated with the distance to the urban market. This implies subsistence farmers and banana producers far from the urban markets are unlikely to apply fertilizer [19]. Additionally, the rain-fed banana system under increasing droughts complicates the soil nutrition issue since soil moisture is known to affect banana plants' uptake of soil nutrients [17]. Among the biotic constraints, the emergence of BXW has affected banana productivity since 2001 when the disease was first reported in Mukono district in central Uganda [3, 21]. Between 2001 and 2006, the disease spread quickly to all major banana-producing regions because little epidemiological information was available about the abrupt BXW outbreak [21]. The causative bacterium, *Xanthomonas vasicola* pv.*musacearum* (*Xvm*) is known highly transmissible *via* infected plant materials, contaminated farm tools and soil, trade of bananas and its products, and vectors including insects, birds, and bats. At present, its prevalence appears to be at a controllable level in Uganda, but all cultivars grown in the Great Lakes region of Eastern Africa are susceptible with no resistance sources identified [3].

Table 1. Factors indicated to be negatively linked to banana production in Uganda.

Some Factors Associated with Banana Productivity	Reference
Declining soil fertility	[11, 17]
Inadequate soil moisture/droughts	[11, 17]
Pests (banana weevil, nematodes, *etc*.)	[11, 17]
Diseases (Banana Xanthomons Wilt and Black Sigatoka *etc*.)	[11, 17]
Poor agronomic practices	[19]
Land use changes by urbanization	[19]
Labor shortages	[19]

Banana is mostly produced in three regions of the country, the southwestern, central, and eastern regions [4]. Until the 1990s the central region had been the main banana-producing area, yet the production moved gradually to the west-south where the crop is now grown more commercially [3, 22, 23]. A study finds 85% of the sampled farms in the southwestern region sold bananas, compared to around 45% in the central and eastern regions [24]. Nonetheless, even in the commercialized west-south region, only 10% of the sampled farms produced bananas purely for income [25]. Therefore, except solely market-oriented farmers, banana producers can be either self-insufficient, meaning their consumption is supplemented by bananas purchased from the market, or self-sufficient, meaning their consumption is met by their own harvest, and surplus may be sold [5].

Regarding the geographical shifts in production from the central to the southwestern, a study shows detailed changes between 1958 and 2016 [9]. In 1958, banana was grown largely in the central (41%) followed by the western (29%) and the eastern areas (27%). In 2016, the western (44%) overtook the central (36%), whereas the eastern and the northern areas occupied relatively small portions, 18% and 2% respectively (Table **2**). Reasons for the geographical shifts include changes in pest-disease pressure, land use, and cropping patterns, as well as soil-water factors [4, 9]. For the pest-disease pressure, it is relatively low in the southwestern region, which is located in the highlands, compared to the other regions that are in the lowlands with higher pest-disease pressure [4]. For the change in land use, competition between urban land use and agriculture is increasing in the central region, which makes banana-plot expansion or new-plot establishment difficult. For the cropping pattern, the decline in banana production in the eastern region is partly attributable to coffee; cultivating coffee on the slope of Mount Elgon has gained popularity as coffee generates a higher profit-to-volume ratio [9].

Table 2. Banana production shares and changes among administrative regions in Uganda.

Data Referenced and Modified from [9]				
Year / Region	**Central Region**	**Eastern Region**	**Northern Region**	**Western Region**
1958	41%	27%	3%	29%
2016	36%	18%	2%	44%

In short, banana is produced under the low input-output system for more subsistence than commercial purposes by smallholders who may need to improve technical efficiency. Over the years, there have been geographic shifts in banana production due to abiotic and biotic pressures, urbanization, land use changes, and cropping patterns. While its productivity hardly shows much improvement, more Ugandans buy matooke under increasing urban development [26]. This suggests the importance of examining its value chain to see how the chain operates, and the following section examines the current banana value chain with relevant issues.

3. BANANA VALUE CHAIN

The banana value chain provides income-earning opportunities to all participants including producers, on-farm and off-farm wage laborers, and self-employed banana collectors, intermediaries, and retailers [25]. In developing countries, agro-commodity supply chains are generally long and complex [1], and that of the Ugandan banana is hardly exceptional; along the Ugandan banana value chain, it is estimated a banana bunch changes hands five to seven times [1, 26]. It should be noted that banana exporters are excluded as the export volume is negligible; in 2020, the banana export amounted to USD 3 million, and only 5% of bananas were suggested to cross the Ugandan border [15, 26, 27].

When banana is sold, over 90% of it is traded individually at farm gates whereas only 2-3% of farmers may sell collectively [24, 25]. Bicycle (or less frequently motorcycle) traders are the first actors to move the harvest along the supply chain, and banana producers may act as bicycle traders when needs arise [26]. Larger commercial farmers can skip bicyclers by selling directly to brokers or wholesalers, but such producers are minor [25]. Bicyclers are mostly male, self-employed, and relatively well-known community members [1, 15]. For bicycle traders, building strong relations with producers is necessary to maximize mutual benefits; bicycle traders collect enough volumes of bananas of good quality at a reasonable price, and farmers often receive information on market demands from bicycle traders [1]. A study finds that 80% of the bicycler-collected banana was sold to brokers at nearby collection centers, and the rest to local consumers, market vendors, and truck traders [1]. Bicyclers likely prefer to transact directly with consumers. If they do, bicyclers save per bunch tax that has to be paid to market organizers [26]. However, for small-scale individual bicyclers, such direct channels are difficult to establish. Challenges that bicycle traders face include price fluctuations and losses during transportation due to the perishable nature of bananas, which gives bicycle traders little negotiation power with brokers [15].

Brokers buy bananas from bicycle traders and often link them with truck traders, playing as commission agents [15]. Brokers possess key market information because they are in regular contact with producers, bicyclers, and wholesalers/truck traders [1]. Additionally, the collusion and informal cartels among the brokers further strengthen their market power by blocking new entrants to the value chain [13, 26]. Wholesalers or truck traders purchase bananas from brokers and transport them to major urban markets in Kampala, Jinja, or Entebbe [15, 25]. Truck traders, mostly self-employed, may not have much incentive to transact directly with banana producers because the producers are scattered across rural areas with poor road conditions. They instead build a close relationship with brokers to stock bananas in quantity and quality [15]. Brokers may compel wholesalers to advance cash, or sometimes wholesalers employ brokers. This tight business relationship often categorizes the two together as intermediaries [15, 25]. Major constraints for truck traders include postharvest losses and high operational costs. Many truck traders do not own a truck, thus the transportation cost likely represents their highest operation cost [15]. Wholesalers sell banana bunches mainly to urban retailers, or directly to consumers [1].

Banana retailers include supermarkets and market vendors [15]. Market vendors are largely female and sell bananas to consumers at markets, alongside roads and major highways, and to commercial establishments such as restaurants [1, 15, 25]. The banana forms sold at this node are bananas in bags, heaps of unpeeled or peeled bananas based on buyers' needs as well as bunches [15]. A challenge for retailers is a very limited timeframe to sell, and this is part of the reason that a matooke cultivar, Kibuzi is relatively popular among traders for its longer shelf life [1, 15, 28]. The banana supply chain ends with consumers [1]. A study finds the majority of banana buyers or 72% are women, and they make most decisions related to purchasing it. Consumers tend to develop solid relationships with their respective sellers over time for fair prices, good quality bananas, and the ability to purchase on credit [15].

In terms of profits, banana producers could be generally considered the least profitable node, but some studies argue otherwise. For producers as the least profitable node, an article reports when a 40kg banana bunch cost UGX (Ugandan Shilling) 25,000 in a major city, brokers sold it at UGX 20,000 while paying farmers UGX 4,000 [13]. Another study estimates similarly; with the banana farm gate price UGX 3,000, the price rose from UGX 6,000 to UGX 25,000 from brokers to consumers. The current value chain structure probably allows middlemen to draw higher profits by holding market information [1]; middlemen come with set prices that farmers accept being unaware of prevailing market prices [13]. However, other studies argue power dynamics between banana farmers and intermediaries may not be as straight as indicated.

Taking into account the cost structure and seasonality, a study shows that per-unit profit margins earned by wholesalers (the term lumps both wholesalers and brokers) were in fact lower than those earned by farmers and retailers. Their lower per-unit profit margins were partly attributed to their higher operational costs, and most profits made by wholesalers were linked to their large trade volumes, which in turn can be their business risk [25, 26]. Seasonality is suggested to cause small shifts in market power between farmers and wholesalers. In peak season, the intermediaries seem in a better position with banana oversupply whereas farmers do in off-peak season when banana is less abundant. And in off-peak season banana becomes less perishable by the slowed ripening process, enabling farmers to wait for better prices [25].

Moreover, the often-mentioned information asymmetry between farmers and intermediaries may not be as severe due to technical advancement. Mobile phones in particular have helped reshape the information asymmetry issue, favoring farmers; mobile phones allow producers to learn prevailing banana prices in urban areas, and to make mobile transactions with other middlemen [26]. Yet in remote areas, local monopsony may rule banana production where fewer communication channels and intermediaries exist [25]. Geographic differences probably exist in the banana market power dynamics as well. For instance, producers in the southwestern region appear to have more bargaining power than the eastern and the central. Since the southwestern producers are more market-oriented, they likely have more experience in dealing with middle actors and searching prevailing market prices [24].

Despite the mixed findings in producers' market power, what appears persistent is low banana farm-gate prices, and the lack of producer cooperatives is repeatedly suggested as a reason for the low farm-gate prices [13, 19]. Functional cooperatives allow group members to share market information, exercise economies of scale, and strengthen the bargaining power of producers. On the other hand, belonging to cooperatives involves costs such as membership fees and inconveniences such as delayed cash income for farmers [26]. In the context of Ugandan bananas, forcing farmers to establish cooperatives may not fit the reality of banana farming. Banana, unlike coffee, is difficult to store, continues producing fruits year-round, and runs under an informal market system. In fact, the insignificant collective trade of bananas occurs *via* producer groups that were formed for other crops, for example, maize [26]. Allegedly, the lack of banana cooperatives is also attributed to the Ugandan authorities; the government appointed its people as cooperative managers, and cooperatives could hardly function when the managers were incompetent or corrupt [13]. Overall, a formal group approach might not suit the situation on the ground, given that the current banana market runs rather flexibly due to the crop traits and social linkages [26]. However, this does not refute that the banana value chain needs improvement.

Postharvest losses and the absence of standardized banana grading systems are often indicated as areas for improvement [14, 15]. Studies estimate banana postharvest loss could be up to 45% in Uganda while the exact scale of loss depends on the season and the node of the value chain. At the farm level, the main causes for the loss include ripening, poor harvesting, and theft, especially in the field distant from the farmer's house [14, 15, 28]. At the broker level, they include ripening and bruising. In particular, bruising results in discoloration and exposes bananas to infection that deteriorates the quality and shelf life of the crop. The loss at the wholesale level can occur by theft as well as ripening and bruising. Theft, different from the producer's situation, happens mainly *via* banana-finger plucking; some workers pluck fingers when loading and offloading banana bunches. This causes both loss and quality deterioration [15].

In Uganda, banana is traded rather arbitrarily in the near absence of standardized criteria [15]. Currently, the bunch size, ripening state, and cooking quality are utilized as informal criteria. Of the three, the bunch size appears the most important because payments including market fees and labor costs are charged per bunch regardless of bunch weight. The ripening state is also important because if a bunch is too ripe, buyers avoid purchasing it. Consistency or softness of banana is critical because matooke is consumed fully cooked [16]. However, those de facto criteria can be rather subjective and rely on visual inspection. In a study, the majority of market actors suggested introducing a weight-based system would improve fair pricing and efficiency even with a potential for added operation costs. On the other hand, retailers and consumers appeared less enthusiastic about the weight-based system, concerning traders using false weighing scales [15].

In short, the findings on the present banana value chain of Uganda are mixed, and imply the value chain may not particularly ill-treat banana producers. The findings indicate a formal group or system approach unlikely fits the informal nature of the existing market structure. However, government attention is needed to reduce transaction costs and improve efficiency. In this regard, promoting postharvest technologies and introducing grading criteria could be prioritized as public intervention. Further, to reduce transaction costs, improving road conditions is fundamental. Poor road conditions increase transaction costs for all value chain actors, and banana losses are estimated highest when the road is poor and impassible during rainy seasons [1].

4. BANANA VARIETIES AND HYBRID ADOPTION

Options for banana consumption and utilization may start with varietal selections at the producer level. Ugandan banana farmers maintain high on-farm cultivar diversity as individual cultivars have distinct end uses and roles to play in diverse settings [7, 10]. Growing a variety of banana cultivars ensures year-round harvesting to accommodate household consumption needs, and bring smaller but continuous cash income [7, 22]. Maintaining cultivar diversity thus helps banana farmers smooth their income and ensure food security. Moreover, preserving banana diversity might support farmers to manage abiotic and biotic pressures better under the current production system, which is labor-intensive and low in inputs, because each variety has different strengths and weaknesses [8].

Studies confirm varietal diversity in Uganda. Over 85 different endemic varieties of matooke were found to exist [29]; 95 banana varieties were identified across the sample households; a typical household cultivated an average of seven varieties with a maximum of 27 [8]; on-farm cultivar diversity ranged from four to 16 varieties with an average of ten [28]; the number of distinct varieties per village ranged from 13 to 38 with an average of 23 varieties; most banana producers grew more than three distinct cooking-type varieties with an average of seven [8]; up to 29 cultivars were grown across villages in southwestern Uganda (Table **3**) [30]. Under such varietal diversity, no single variety dominates in the country, and even the most widely grown varieties are estimated less than 10% of banana stands [8].

Table 3. Number of banana varieties identified from sampled areas in Uganda.

Data Referenced and Modified [8]			
Analysis Unit	**Household Varieties**	**Household Cooking Varieties**	**Village Varieties**
Low elevation	6.72	4.01	22.41
High elevation	9.07	6.38	28.54

To select varieties, Ugandan farmers employ their own criteria depending on the main production purposes. The relative importance assigned to different varietal attributes affects trade-offs that farmers make when selecting the type and the number of varieties to grow [8]. Studies identify a range of criteria for cultivar selection, and up to 22 varietal traits were mentioned [28]. From the agronomic perspective, key characteristics frequently mentioned are bunch size, finger size, cultivar longevity, marginal soil tolerance, early maturity, drought tolerance, pest resistance, toppling, marketability, appearance, stem sturdiness, and planting material availability. From the consumption perspectives, they include yellow color, homogeneity of the color, moistness, smoothness, moldability, taste, and aroma [2, 10, 23, 31]. Popular local varieties tend to possess some superior qualities both in the agronomic and consumption characteristics, yet no single cultivar meets all preference criteria [10].

In the western and southwestern regions, *i.e.* the leading banana-producing areas, the most grown include Kibuzi, Mbwazirume, Musakala, and Nikitembe, and the varietal preference appears strongly associated with banana growing objectives. For example, semi-commercial farmers likely grow Kibuzi because the variety is preferred at the market for its longer shelf life and larger finger size [15]. The banana finger size is often mentioned as critical for selection; to males, it is a key market trait for sale whereas to females, small fingers are difficult to handle for food preparation [10]. A study in the central and western regions suggests the most preferred varieties include Kibuzi, Mbwazirume, Mpologoma, Musakala, and Nikitembe [10]. Mpologoma is considered very popular because of its large bunch size, which makes the variety called a money maker or a lion in the Luganda language [28]. In a different study in the central region, Mpologoma and Nikitembe are perceived as the most desirable for their superiority in taste and bunch size [23].

Banana production in Uganda has not improved much due to the constraints as previously mentioned, and favored local varieties tend to be more vulnerable to those constraints [10]. In 1994, the National Banana Research Program of Uganda initiated a breeding program to develop matooke hybrid varieties, and to date, seven cooking-type hybrids have been released [2, 32]. Initially, banana hybrids were introduced to counter the Black Sigatoka disease [11]. It has been rampant in lowlands covering most of the central and eastern regions, and severely constraints matooke production [33]. The disease may result in small bunches, poorly filled fingers, and loss of over 50% yield [34]. The disease can be managed by the fungicide, but high costs and limited availability of the chemical make the fungicide option impractical for resource-poor banana farmers. Thus, the development of hybrids resistant to Black Sigatoka came across as a realistic intervention option [34].

The overall matooke breeding efforts have focused on enhancing productivity through the development of pathogen-resistant high-yielding varieties with adequate stability [35]. Yet studies indicate matooke hybrids that are superior in agronomic traits but inferior in consumption characteristics are often rejected, contributing to low adoption of banana hybrids in Uganda [2, 10, 19, 32]. One study finds only 14% of the sampled farms reported growing matooke hybrids, and another study shows none of the sampled farms grew only hybrids whereas 51% grew only local cultivars [23, 36]. Also attributable to the low hybrid adoption are risks associated with growing hybrids [2]. FHIA, an initially introduced hybrid was not successful because cultivating FHIA was linked to increased labor burden by requiring bigger holes, more crop residue, and de-leafing to produce large fruits [2, 36]. This hybrid is now grown in low numbers solely as a food security backup [28].

In the context of Ugandan banana farming, studies suggest factors that influence farmers' uptake of improved hybrids (Table **4**). First, the education level of a farmer was negatively associated with the likelihood of adopting banana hybrids [2]. A possible explanation is less educated farmers may have larger households, and thus take more interest in improved hybrids for their higher yields [11, 36]. Second and relatedly, the household size was positively related to the demand for banana hybrids. The household size can be an indicator of food consumption requirements, therefore production advantages of hybrids are likely to attract larger households [11]. The household size can also indicate farm labor availability, which is needed to produce more in absolute terms [36]. Third, farmers managing larger land were more likely to plant new banana hybrids. Those farmers are probably more willing to take risks by allocating a portion of their land to new varieties [11]. Additionally, larger land is required to produce bigger perennial crops such as bananas [3, 11]. Similarly, a different study finds that hybrid banana adopters owned more total land [36]. Fourth, male farmers were more likely to plant new banana hybrids than female counterparts. Male farmers in Uganda are more commercially oriented with tighter control over household cash income, therefore more interested in market-oriented improved hybrids. This gender disparity is possibly connected to farmland accessibility as well; male farmers tend to have better access to land, which may be required for new banana hybrid adoption [3, 11]. In contrast, a study in eastern Uganda shows female farmers had a higher probability of adopting banana hybrids than their male counterparts. An explanation is that banana in this area is considered a woman's crop for household food security, thus female farmers value hybrids for their higher yields. Fifth, the age of a farmer shows mixed results on hybrid adoption. One study shows that farmer age was not significantly associated with hybrid banana adoption while in a different study, older farmers were more likely to plant a new hybrid only when the hybrid resembled a local variety [11, 36]. Sixth, rather than the farmer's age itself, the number of years with hybrid production appeared negatively associated with hybrid adoption. Farmers may be less willing to grow new varieties after having observed undesirable traits in banana hybrids [36]. This reasoning could cut both ways, however; the more they experience satisfactory results with hybrids, the more likely they are to try new hybrids. Seventh, distance to the nearest market could affect banana hybrid uptake. Farmers farther away from the nearest market were less likely to plant new hybrids in large quantities. Those farmers are generally less market-oriented and focus more on meeting their subsistence needs and preferences [11]. Thus, local varieties with preferred consumption traits are likely chosen over new hybrids with improved market traits. Eighth, the source of banana planting materials was associated with the adoption decision. The most important source of planting materials was fellow farmers for initial hybrid planting, followed by research institutes and community leaders. Access to reliable planting materials however does not always guarantee hybrid uptake since farmers evaluate candidate varieties as a whole with their own criteria [36].

Table 4. Factors affecting banana hybrid adoption and their relations in Uganda.

Factor Identified	Association with Banana Hybrid Uptake	Reference
Education level	Negative	[2, 11, 36]
Household size	Positive	[11, 36]
Farmland size	Positive	[3, 11, 36]
Farmer gender	Positive (male) #	[3, 11]
Farmer age	Mixed	[11, 36]
Hybrid farming year	Negative	[36]
Distance to market	Negative	[11]
Source of banana hybrid	Fellow farmer (most important)	[36]

Note: # in eastern areas, positive with being female.

Once a hybrid adoption decision is made, adoption intensity is important for sustained cultivation of adopted varieties as farmers increase or decrease the area planted with banana hybrids. A study shows farm households that interacted more with agricultural research stations, extension agents, and banana traders had more banana hybrid mats than those who interacted with fewer or no other actors. Such interactive linkages are important for information flows about variety attributes, utilization, and potential benefits, which all enhance farmer knowledge and confidence in banana hybrids [36]. This underscores the roles played by key actors in hybrid dissemination and promotion. However, it cannot be excluded that those actors do target farmers who have already adopted hybrids. For adoption intensity as well as the initial adoption decision, the source of banana planting materials appeared essential; hybrid adopters had more confidence in planting materials provided by reliable sources such as public agencies [36]. This emphasizes the importance of dependable supply systems of banana planting materials under proper supervision, and indeed banana farmers ranked the provision of quality planting materials as an urgent issue that needs government assistance [24]. The following examines where Ugandan banana producers source planting materials and how the materials are disseminated.

5. DISSEMINATION OF BANANA PLANTING MATERIALS

As banana propagates vegetatively, banana plantlets or suckers can technically be considered seeds. Banana planting materials are relatively bulky, highly perishable, difficult to store, low in production rates compared to true seed crops, and prone to easy pathogen build-up that affects seed health [22]. Those attributes influence the way banana farmers select and manage planting materials. Banana producers seek to source planting materials when they establish a new banana field, try out new cultivars, and expand the existing field. Or they need planting materials when the existing banana plot has gaps to fill as it is highly unlikely all banana plants die off at once.

Farmers generally have two options for sourcing planting materials, the formal and informal systems. The degree of farmers' utilization of the two systems may depend on the dominance of one system, crop traits, and farmer characteristics [22]. The formal system is characterized by the production and distribution of seeds of registered varieties, and by strict measures for seed quality control. The formal system, however, involves higher cash requirements, transport costs, and fewer social relations between a buyer and a seller. The formal seed sources of Ugandan bananas include national agricultural entities, laboratories, research institutions, nurseries, and non-profit organizations.

For vegetatively propagated crops in developing countries, the informal (also called local, traditional, or farmer) seed system is dominant. This is the case for banana planting materials in Uganda, and the informal channels include neighbors, relatives, other farmers, and farmers' own farms [22]. Studies suggest most Ugandan banana producers source planting materials from their own farms; about 60-70% of the sample banana mats originated from farmers' own farms [7, 22]. Yet, banana farmers seek planting materials off-farm when they have insufficient suckers available on their own farms, observe high-performing cultivars on others' banana fields, or are interested in new varieties. For insufficient on-farm suckers, banana suckers available for a specific cultivar can be limited since banana fields typically consist of a mixture of different cultivars [7]. Some suckers such as water suckers are unsuitable for planting, and suckers closest to mother plants must be left intact for banana mat continuity. Thus, on-farm suckers available for planting are those left after excluding suckers unfit for planting and key to banana mat maintenance [28].

Obtaining off-farm planting materials is shown strongly influenced by social ties and cultural norms, and seldom involves monetary transactions [22]. A study identified that 70% of the off-farm banana planting materials were a gift, and the rest 30% involved monetary transactions ranging from UGX 500 to 1,500 [7]. By acquiring planting materials from familiar or nearby sources, farmers can predict the agronomic performances of the materials since they know the sources and the materials are likely adapted to their local agroecological conditions [7, 22]. To obtain off-farm banana suckers, farmers evaluate holistically the sucker, mother plant, mat, and farm management of the source farmer. This could be more easily done within their social networks [7]. In other cases, the source farmer offers or sells uprooted suckers without providing the receiving farmer with key information about the suckers. This makes off-farm sourcing outside the social circle riskier, and securing quality planting materials may hinge on a farmer's social capital [28]. However, demands for off-farm banana suckers are highly irregular due to the perennial nature of banana plants, high on-farm cultivar diversity, use of one's own planting materials, random replacement of banana mats, and different practices in mat management. Those traits make a demand of off-farm suckers highly unpredictable [7].

Sourcing planting materials through informal channels, either on-farm or off-farm, does not ensure they are clean. Combined with inadequate agronomic practices, unclean suckers often serve as a route for banana pest-disease transfers [7]. Around 2008 as a public intervention, a tissue culture (TC) program introduced clean banana plantlets to the central region which had been heavily affected by the disease BXW [22, 28]. Despite the presumed benefits of using clean planting materials, sales of TC plantlets through the formal channel dropped after the program ended; some nursery owners mentioned up to 70% decline in sales. In general, the use of TC plantlets remains low among Ugandan farmers [22].

Farmers' reluctance to accept TC plantlets may be explained by economic and management factors. Farmers need to purchase TC plantlets and follow through with more demanding cultivation practices that are often labor-intensive with additional input requirements for optimum performances. This entails increased production costs and potential changes in farm management practices [3]. Additionally, farmers are concerned that the purchased TC plantlets would turn out unwanted varieties as the plantlets are hardly identifiable until fully grown [28]. Some farmers even perceive TC plantlets are genetically modified, thus are unfit for their banana farming [3]. A study in the central region suggests farmer decisions on TC plantlets were all influenced by seed security factors (acceptability, accessibility, adaptability and availability), farmer competence, social influence, and socioeconomic factors [37]. This implies decision-making on banana planting materials is not simple.

From a perspective of sociocultural values, a study in the central region argues TC banana varieties are little compatible with diverse cultural usages of bananas when the crop is considered a cultural artifact as well as food and income sources. The cultivars preferred in this region therefore are not necessarily market-oriented, and may possess specific traits related to cultural practices [3]. Currently, few varieties supplied *via* TC meet such usages, and TC rarely offers varieties preferred by females for home consumption. For instance, TC matooke cultivars such as Mpologoma, FHIA-01, and FHIA-17 are perceived to have undesirable cooking traits including whitish color, little aroma, and flat taste [3].

To summarize, when selecting sources for planting materials, banana farmers seem to consider source locations, transaction types, availability of knowledge, trustworthiness, timings of planting materials available, and investments required for management [22]. Access to planting materials is likely conditioned by social relations and community cultures as well as biological traits of banana plantlets and farming practices [38]. While banana plantlets in Uganda are circulated through informal channels, there seems little evidence supporting that the informal seed system is nonfunctional. Rather, the existing system allows banana producers to source planting materials based on their needs, preferences, and means. However, the quality of plantlets sourced on-farm and off-farm cannot be guaranteed, and this may contribute to the spreading of pests and diseases across banana fields. The TC program provides clean planting materials, but the varietal options are too limited for noticeable uptake. Nonetheless, satisfying the broad varietal need is not viable for TC business because of the unpredictable or low demands of each variety. Given the situation, the government policies should focus more on how to best utilize the current informal system to promote clean platelets.

6. GENETICALLY MODIFIED MATOOKE FOR ENHANCED PRO-VITAMIN A

Uganda was the first country in Africa where studies on vitamin A (VA) were carried out [12]. Vitamin A is an important nutrient supporting vital human physiological and developmental functions. It is estimated that up to a third of Ugandan children under the age of five suffer from VA deficiency (VAD) while a possible decline in VAD is indicated [29, 39]. Matooke is deficient in VA or plant-derived pro-vitamin A carotenoids (PVA), mainly α- and β-carotenes. The overreliance on matooke arguably contributes to exacerbating VAD in the country, but simultaneously makes matooke a valuable food vehicle to deliver PVA through biofortification [40, 41]. Conventional breeding methods to develop PVA-biofortified matooke are constrained by its low genetic variability, polyploidy nature, female sterility, limited seed production, and high costs for space and time requirements [23, 34].

Alternatively, genetic modification (GM) was utilized to enhance PVA in local matooke cultivars, and the vegetative reproduction of banana plants offered additional advantages to the GM approach [40]. Upon purchasing, farmers own the offspring of GM plants, unintended gene flows are predicted at a minimum level, and the GM version would not jeopardize international trade as matooke is consumed domestically [29, 42]. A project called Banana 21 succeeded in isolating the phytoene synthase gene that confers high levels of PVA from a banana variety, Asupina, native to Papua New Guinea. The gene was transplanted into matooke hosts with the aim of PVA 20 µg per gram. This was set to meet 50% of the estimated average requirement for the target demographics with 300g per capita daily matooke consumption [29, 40]. Distribution strategies were also devised to disseminate the PVA-biofortified matooke plantlets; upon plantlet propagation *via* TC, select farmers would receive the PVA banana suckers and later give two for each sucker they received to neighbors. The receiving neighbors in turn would be asked to give away two for each they received [40].

Since matooke is consumed cooked, the efficacy of PVA after the cooking process is key to mitigating VAD. A study that measured retention of carotenoids concludes the two crucial carotenoids, α- and β-carotenes were retained at least 70%. Matooke is typically purchased in bunches and stored until fully consumed or up to 14 days postharvest. It is reported the storage period improved carotenoid accumulation up to 2.4 folds in Nakitembe, a local cultivar selected for PVA biofortification [43]. A study estimates the cost-effectiveness of the PVA project by measuring the disability-adjusted life year (DALY) with a matooke hybrid M9, assuming an adoption rate of 40% pessimistic and 64% optimistic. Taking the full cost of research and development into account, the GM M9 could save 19% DALY under the pessimistic scenario in comparison to the baseline DALY, and 40% under the optimistic scenario. These findings suggest that GM PVA matooke is cost-effective based on the criteria by the World Bank and World Health Organization [41].

Even with those promising findings and results, issues have emerged for wide adoption and consumption of the GM PVA matooke. The issues are closely related to the altered color of PVA matooke flesh, disparities in prioritized crop traits, host cultivar issues, reservations on plantlet delivery channels, and acceptance of GM matooke (Table **5**) [29].

Table 5. Potential obstacles to wide adoption of genetically modified pro-vitamin a matooke in Uganda.

Referenced and Modified from [28, 29, 33]	
Potential obstacle	Reason
Color alteration	Pale yellow to orange
Farm priority	Nutrition in low-rank
Host variety	Not prevalent variety
Delivery system	High price *via* formal seed system
GM legal status	Uncertain legal status of GM crop

First, the color alteration from yellow to orange of the PVA matooke can substantially affect acceptance or more precisely, lead to rejection. The enhanced β-carotene changes the color of the prepared dish to light orange, which is supposed to be soft yellow. With the color change, an optimistic prediction may be that large-scale awareness campaigns with nutrition education could convince farmers and consumers, similar to the successful promotion of the Orange Fleshed Sweet Potato. A pessimistic prediction is that the color change becomes a persistent barrier to consumption, and interest in the PVA matooke decreases. Even the optimistic case may take considerable public efforts since the soft yellow color in matooke and food is one of the highly valued consumption traits.

Second, concerning the prioritized crop traits, a study finds the surveyed farmers ranked nutrition relatively low, compared to other crop characteristics. The finding reveals farmers prioritized traits associated with yield, marketability, and pest-disease resistance over nutritional improvement because nutrition is not a trait that translates into higher market prices. Furthermore, farmers tend to understate the enhanced nutrition, by mentioning they are confident in meeting the nutritional needs with their current diet.

Third with the host variety issue, the prevailing local varieties such as Kibuzi, Mbazirume, and Mpologoma were excluded as they were unsuitable for the GM transformation process. Nakinyika, one of the first hosts for the PVA-enhancing gene is a traditional variety, but not widely cultivated throughout the country; in a survey, 21% of farmers chose to grow it. Nakinyika is considered to produce smaller fingers that limit yields, and its texture makes mashing difficult which lengthens food preparation time. Another host, Nakitembe appears more popular, and 30% of the surveyed farmers chose to cultivate it. A hybrid matooke, M9 with other names such as Kabana 6H, Kiwangaazi, or a Kawanda variety stands promising since it is considered resistant to Black Sigatoka and BXW, and tolerant to weevils and nematodes without compromising yields [33]. Its resistance and tolerance to the stressors also confer its local name, Kiwangaazi meaning the one that lasts for a long time [29, 33]. Even with those advantages, farmers revealed their skepticism towards M9. The hybrid was ranked low in taste and color, and Kawanda varieties are generally perceived as more delicate and labor-intensive to grow [28, 29].

Fourth with the plantlet delivery, farmers should purchase TC plantlets although not paying for the license associated with the genetic transformation in the PVA matooke. Regarding purchasing prices, a TC plantlet at nurseries could cost up to UGX 3,000, compared to free suckers from neighbors or as little as UGX 500. A willingness-to-pay (WTP) analysis shows when a new GM variety costs four times more than a non-GM equivalent, the opposition to a new GM variety becomes significantly stronger [29]. A different study finds that the mean WTP per GM sucker ranged from UGX 1,092 to 1,702 with regional differences for GM acceptance [5]. Those findings suggest considerable price resistance can be expected if the present prices of TC plantlets are applied. Dissemination of GM plantlets will essentially blur the line between the formal and informal seed systems; after purchasing plantlets through the formal channel, farmers are free to replant, exchange and sell subsequent suckers. And these farmer-supplied GM materials might not be properly regulated for their quality and status for diseases and pests.

Fifth, a broader issue with the PVA matooke is the approval of GM crops because Uganda lacks a regulatory framework for biotechnology application as of this writing. The National Biotechnology and Biosafety Bill 2012 was introduced to the Ugandan Parliament for a regulatory framework that would guide biotechnology applications and minimize potential risks [39]. The Parliament passed the Bill into law in 2017, which became the Biosafety Act 2017 [40]. Assuming that the law is passed, the GM PVA matooke still needs to clear the air around GM crops. A study concerning GM bananas in Uganda concludes the better-off and better-educated demographic segments appeared more against GM bananas both in urban and rural regions [42]. In western and central Uganda, the maximum adoption rates of GM bananas were estimated at 56% and 35%, with an average of 43% across the two regions [41]. One study further explores what variables would influence Ugandan farmers' attitudes toward GM bananas [4].

In the first place, farmers in eastern and southwestern Uganda appeared to hold more positive attitudes towards GM matooke than farmers in the central who expressed greater reticence towards GM matooke. The regional variation is explained by matooke production purposes and a mixture of historic and geographic factors. Banana in central Uganda has been cultivated within the Buganda kingdom since the 15^{th} and 16^{th} centuries. This traditional importance of matooke remains persistent in this region, and other regions hold less of such significance in matooke. In terms of urban and rural localities, the more urbanized areas seemed less willing to accept GM matooke. The difference is explained by that rural inhabitants are poorer and grow bananas more frequently, thus they are more likely to experience welfare gains from GM bananas. In contrast, urban consumers who are generally wealthier and more educated are likely to experience welfare losses given their concerns about potential health and food safety issues with GM crops [42]. The varied attitudes between the rural and the urban could arise from uneven degrees of opposition against GM crops. Urban residents may be more exposed to the critical views on GM as Kampala, the capital city, is home to most civic organizations expressing concerns about the country's push for GM. Moreover, a study argues the negative views on GM bananas from the Ugandan urban elite are from their views more aligned with European countries on GM [42].

Second, farm size appears positively correlated with the attitude toward GM bananas; the larger the farm is, the more likely farmers hold positive attitudes toward it [4]. Farmers with larger land are probably more integrated into the market system, hence more confident in selling the increased yields of GM bananas. Considering the larger farm is often a proxy for wealth, GM bananas may be more favored by wealthier farmers who are better positioned to take risks associated with GM matooke adoption. A different study observes a similar finding with wealth; banana producers with higher income were more likely to purchase GM banana suckers [5].

Third, belonging to a farmer association was positively associated with farmer attitudes and intentions to adopt GM matooke [4]. This echoes the importance of social networks and peer influence on the uptake of new technologies as discussed with banana hybrids and TC plantlets. Farmer associations serve as key venues through which farmers exchange essential information to make adoption decisions, gain confidence in their risk-taking, and share knowledge on the best management practices with GM varieties. However, such information flows may go both ways because negative attitudes toward GM varieties can spread *via* social networks.

Fourth and related to information-knowledge flows, farmers who were visited by extension workers had more positive attitudes toward GM bananas than those who never visited [4]. Farmers visited by extension workers have more confidence in the government's ability to protect them from the potential negative effects of GM. Many Ugandan farmers identified insufficient access to extension services as the most pressing obstacle to the adoption of new agricultural technologies. Yet, the existing access to extension services is viewed as uneven among Ugandan farmers; smaller, poorer, and female farmers tend to have less access to such services. The uneven access implies potentially heterogeneous GM banana adoption and benefit-sharing among banana producers when extension services play key roles in its dissemination.

The aforementioned variables for GM banana adoption are, to some degree, associated with wealth, integration into the formalized networks, and access to key information. This may raise questions about who may benefit the most from the GM PVA matooke, and its blanket rollout might miss out the most vulnerable segments of the population.

CONCLUSION

Banana or matooke holds an unparalleled place in the livelihood of Ugandans, serving as a food security crop, an income source, a main dish, a cultural artifact, and other daily purposes. The current banana sector of Uganda appears functional under the organized informality, however, some technical, agronomic, and sociocultural issues were identified across the matooke value chain. Given the limited availability of public funds, the government may have to select and focus on some improvement areas.

In the first place, public support can pay more attention to strengthening banana producers' production techniques without compromising the unique varietal diversity. Improving the banana production techniques of farmers could be a better option than pressuring farmers to adopt matooke hybrids or make a heavy investment in inputs. In doing so, the government assistance may start with better delivery of extension services. Strengthened extension services would be more effective in enhancing banana productivity because farmers are already familiar with their local cultivars and agro environment while in need of updated production techniques and knowledge. Disseminating improved hybrids that require management changes and more input investment might not fit the reality of risk-averse smallholder banana producers. Also, extension services may include strengthening producers' capacity to screen and self-regulate banana planting materials for the quality and disease-pest status. Due to the multiple factors aforementioned, establishing a formalized seed system for banana planting materials is unlikely to function as intended. Instead, it would be more effective to enable producers to do the checks. The reviewed studies suggest that Ugandan farmers trust extension services as a reliable channel for obtaining information, therefore the government should direct more resources to fortify the accessibility, availability, and quality of extension services for banana farmers. Yet, the near absence of banana producer groups may restrict extension services from transferring techniques and knowledge to farmers effectively. This could be fixed by maximizing the utilization of existing groups for other crops. It is highly likely that the majority of those group members produces and trades banana individually. Thus, the existing groups can be mobilized to efficiently transfer technical information and motivate banana producers to learn from one another.

Besides transferring production techniques and knowledge, public assistance can offer the value chain participants training on postharvest handling and banana quality grading to help reduce losses and institute a standardized grading system. Systematic training on postharvest handling will cut losses and prevent quality deterioration, which benefits all value chain participants. Furthermore, establishing an agreed grading system could incentivize farmers to produce bananas that meet the standard, and traders to operate more transparently. Finally, the government and international donors who are interested in rural development can collaborate to upgrade road conditions even though it is a tall order in the short term. Investment in feeder and main roads to the major matooke markets is necessary to reduce transaction costs, and any agricultural and rural development in Uganda would not be sustained without better road conditions.

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CONFLICT OF INTEREST

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