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REVIEW ARTICLE

The Current Status and Constraints of Drought-Tolerant Maize Adoption in Uganda

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Abstract: Agriculture is an economic backbone of many sub-Saharan African countries, including Uganda. However, the country is grappling with slow agricultural development and food insecurity. Concurrently, Uganda faces climatic challenges that likely become further constraints for agricultural production. Maize is one of its major crops and serves as a food and cash crop for smallholders. However, its productivity remains low. To improve maize productivity under increasing temperatures and droughts, drought-tolerant maize (DTM) has been released, but it is not widely adopted.

The objective of this study is, therefore, to review the current situation of DTM adoption in Uganda and identify characteristic differences between adopters and non-adopters and possible constraints for wider adoption. In doing so, available literature, policy documents and relevant reports on the subject were reviewed. The systemic approach was not feasible due to limited availability of reliable sources.

Drought-tolerant maize adopters in Uganda appeared to be better endowed with production resources such as larger farmland, be more informed, educated and experienced, have a larger household, use more inputs more efficiently, earn higher income and harvest better yield. Major constraints to DTM adoption included lack of awareness, limited seed availability and accessibility, complementary input requirement, existing DTM attributes and dubious market quality of seed and fertilizer. These constraints and adoption characteristics seemed intertwined as a virtuous or vicious cycle for DTM adoption.

Although a broad range of DTM adoption constraints is identified at a household, market and national level, DTM can be an effective means to improve maize productivity under climatic challenges in Uganda. To promote its adoption, the government should take more supportive measures and effective strategies for sustainable DTM uptake.

Keywords: Agriculture, Climate change, Drought-tolerant maize, Food security, Sub-saharan africa, Uganda.

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1. INTRODUCTION

Agriculture is the economic mainstay of Uganda contributing 46% to the total export earnings and 25% to the Gross Domestic Product (GDP). Agriculture also employs 72% of the total population and up to 87% of them live in rural areas [1]. Yet, most of the rural population or 62% depends on small-scale farming at a subsistence level and about 30% of them are estimated below the national poverty line [1, 2]. Despite its importance, the average annual growth of agriculture in Uganda has been slow in recent years. The growth rate of agriculture was 2.2% during the period of 2010-2014, whereas the average annual growth rates of GDP and population were 5.2% and 3%, respectively [1].

Also, its level of food security is low. The 2019 global food security index ranked Uganda 98th out of 113 indexed

countries [3], its prevalence of undernourishment was 41% on three-year average across 2016-2018 [4] and 2019 global hunger index was 30.6 or an alarming level of hunger [5]. Considering its heavy reliance on agriculture and low level of food security, development in agriculture helps reduce rural poverty, improve food security, and subsequently catalyze development in other economic sectors [1]. Nevertheless, the agricultural development of Uganda has been hampered by many challenging issues. One of them is that most smallholder farmers remain subsistence-orientated with low productivity [6]. Moreover, they cultivate low-value crops mostly under a rain-fed system that becomes more vulnerable to increasing temperatures and decreasing rainfalls due to climate change [7].

Maize (*Zea mays* L.) is one of the most important cereal crops in Uganda, particularly for smallholder farmers. Approximately, 86% of the rural population grows maize and the crop plays both as a food and cash crop for most rural households [8, 9]. Maize is considered relatively easy to

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cultivate, adaptable to different soil types and flexible with various cropping systems: it can be grown in a pure stand (47% of the total maize plots in Uganda) or mixed with other crops (53%) such as groundnut, rice and bean [10, 11].

When the nutritional contribution of maize is measured as caloric intake, approximately 40% of the calories were obtained from maize and in some districts higher than 60% [10]. It is also a major staple for the urban poor and public institutions, mainly schools, hospitals and military institutions [9].

Maize is a strategically important export crop as well. The main export market of the crop is the East Africa Community member states where maize plays a larger role in their local diets [12, 13]. Kenya accounts for over 50% of Uganda's total maize export. And high demands from other countries such as Democratic Republic of the Congo, Southern Sudan and Rwanda provide Uganda with a growing export opportunity. At the same time, informal or unofficial cross-border trades of maize are reported to increase [10]. Estimated 65% of the informal export occurs mainly with grain to Kenya and flour to Tanzania, Rwanda, Congo and Sudan [13].

Over the years, the total maize production in Uganda has been gradually increased [14]. However, large part of the production increase is explained by a steady expansion of maize acreage, little by improved productivity [12]. Accordingly, low maize yield is one of the highlighted issues that the maize industry of Uganda faces. The current maize yield ranges from 1.9-2.5 ton/ha, but this hardly reaches the potential 5-7.5 ton/ha, leaving a wide yield gap between the current and achievable level [1, 8, 9]. One reason for the current low maize productivity is that the crop is generally produced under a low input-output system by smallholder farmers [8].

Agricultural growth is not possible without increasing productivity and/or reducing loss because continuing agricultural area expansion is neither sustainable nor feasible. In this regard, agricultural technologies can assist in achieving the agricultural growth and such technologies include improved seed, agricultural chemicals, irrigation or water control, mechanization, and tillage methods [15]. However, it is noted that adoption of agricultural technologies is often negatively correlated with risks and uncertainties under a specific environment and importantly affected by a farmer's perception and expectation of technology [16].

In Uganda, even compared to other Sub-Saharan Africa (SSA) countries, adoption of available production inputs and technologies remains limited [17]. For instance, a report found that 21% of maize farmers used improved seed, 9% pesticide, 8% chemical fertilizer and lower than 1% irrigation [18]. Yet, those numbers could be even lower, depending on data sources. One study that utilized a national household survey data indicated 82% of the farmers planted local maize seed, 1% used fertilizer and 3% pesticide [19, 20].

In addition, climate change can alter conditions for crop cultivation by increasing the frequency and intensifying the risks related to crop production [21]. As such, increases in temperature and decreases in rainfall are a serious constraint

for maize production since it is weather-sensitive and vulnerable to climate change [22]. With this concern, Uganda has released improved maize with drought tolerance to ease the burden of smallholder farmers and increase maize productivity. At an African-regional level, over 200 drought-tolerant maize (DTM) varieties were released by early 2016 through the Drought Tolerant Maize for Africa Project in 13 countries including Uganda [23]. Despite the release of DTM from both national and international efforts, their uptake stays low in Uganda [24].

Given the low input-output system dominated by smallholder maize farmers and increasing occurrence of the adverse weather events, this research focuses on the DTM adoption situation in Uganda. It is important to understand the current DTM uptake since it can provide smallholders with a tool to increase maize productivity and reduce production risks. Thus, to better comprehend and promote DTM adoption, this research first briefly reviews the seed sector of Uganda with improved (DTM) seed, second explores characteristic factors that likely affect DTM adoption, and third examines probable causes of the current low DTM uptake in the country.

A systematic approach was not feasible due to limited literature currently available. Nonetheless, findings of this research could help policy makers and international agencies to draw implications for more effective DTM promotion to strengthen food security in Uganda.

2. SEED SECTOR OF UGANDA AND IMPROVED MAIZE SEED

The current seed sector of Uganda consists of two systems: the informal and formal [25]. The informal or local seed system contributes up to 85% of the seed planted in the country. This system is based on farmer-saved seed from their own harvest or farmer-selected landrace seed bred over time. Seed in this system may also be originated or recycled from the improved seed initially sourced by the formal system. Distribution of the seed relies on trades among community members or in rural markets. This system is hardly monitored or controlled by the government regulations. Instead, it is guided by local standards [25]. It is argued that the dominance of this informal seed system in Uganda is partly due to inadequate regulatory capacity of the government, supply shortage of certified seed and low farmer confidence in certified-market seed [6, 25].

On the other hand, the formal system contributes to about 15% of the seed planted in the country [25]. It is a structured channel from seed development, multiplication, quality control, distribution to marketing. The national seed certification service is the government entity regulating the seed industry of Uganda under the Ministry of Agriculture, Animal Industry and Fisheries. The formal system also covers the international seed trades mainly with maize seed for the regional markets. The major players of this seed system are the government, public institutions, and private sectors [25]. Of them, private seed companies play a critical role in maize seed development, production and distribution in the formal system. In 2017, there were 34 registered seed companies in Uganda, of which 19 produced total 21959 tons of maize seed. The maize seed

market of Uganda is considered competitive: the top four company concentration was 69% and Herfindal-Hershman Index 1425 (10000 indicating monopoly) according to the 2018 report [26].

Improved maize seed is categorized into two: open-pollinated (OP) and hybrid. The annual use of the OP maize seed was estimated to be 17655 tons and 8000 tons for the hybrid in 2014. Of 17655 tons of the OP seed, 66% was produced through the informal system and 34% the formal. On the other hand, 100% of the hybrid seed was produced in the formal system [25].

Over the years, approximately 71 improved maize seeds have been developed and released with various attributes such as high yield, resistance to pest and disease, early maturity, drought tolerance, nutritional benefit and tolerance to acidic soil [8, 23]. Of the improved seeds, 18 were drought tolerant as of this research (Table 1).

Table 1. List of improved maize varieties with drought tolerance and their attributes.

Variety Name	Year of Release	Variety Type	Maturity Period (days)	Potential Yield (Mt/Ha)
Longe 1	1991	OPV	115	4-6
Longe 4	2000	OPV	103	4-6
Longe 5	2000	OPV	115	4-6
MM3	2010	OPV	80	4-6
Longe 7H *	2002	Hybrid	120	8
Longe 9H	2009	Hybrid	125	8-9
Longe 10H	2009	Hybrid	125	8-9
Longe 11H	2009	Hybrid	125	8-9
UH5051	2012	Hybrid	125	8-9
UH5052	2012	Hybrid	125	8-9
UH5053	2012	Hybrid	125	8-9
PAN 67	2000	Hybrid	120	6-8
WE 2101	2014	Hybrid	120	6
WE 2103	2014	Hybrid	120	4
WE 2104	2014	Hybrid	120	5
WE 2106	2014	Hybrid	120	6
WE2114	2014	Hybrid	120	6
WE2115	2014	Hybrid	120	6

Modified from [* from 27, 28].

Currently, some of the most popular improved maize varieties are the longe4, longe5, longe5D, and MM3. The longe4, longe5 and MM3 are OP and drought tolerant. The longe4 and MM3 are popular partly for their early maturity and longe5 its high content of lysine and tryptophan [26]. However, their potential yields are relatively low compared to DT hybrids, ranging from 4-6 Mt/ha vs. 4-9 Mt/ha, respectively (Table 1).

Assuming a stable seed price at a planting time, a ratio of seed-to-grain price may indicate the extent to which the seed is improved as the ratio can reflect the cost of development, production and market transaction. In other words, a low ratio of seed-to-grain price indicates competition between improved seed and farmer-recycled one since their prices are similar.

Among the four major crops in Uganda (maize, bean, millet and sorghum), the hybrid maize seed had the highest ratio (6 to 1) followed by the OP maize seed (3 to 1). The ratios of the other three crops were 1 to 1 for millet and 1.2 to 1 for bean and sorghum [26].

3. CURRENT SITUATION OF DROUGHT-TOLERANT MAIZE ADOPTION

3.1. Drought Vulnerability of Maize Production in Uganda

At a regional level, SSA experienced a 0.2-2.0°C temperature increase during the last several decades [2]. It is also predicted that a mean annual temperature in Africa would be 2°C higher during the middle of the 21st century than the late 20th century under medium scenarios. Despite uncertainty about rainfall changes in SSA, climate change models consistently predicted increasing incidences of drought [29]. As agricultural production in this region largely depends on precipitation and is temperature-sensitive, increases in temperature and decreases in rainfall likely affect rural livelihood as well as agricultural production in negative manners [2].

In Uganda, approximately 75% of farm households rely on rain-fed agriculture and few farmers employ an irrigation system [6, 7]. Negative impacts of drought have already manifested themselves on the country's agricultural production. For instance, the droughts in 2006 and 2008-2011 affected food and livestock production that resulted in higher food prices. And the loss from the 2010-2011 droughts was estimated USD 1.2 billion [2]. In fact, a study found empirical evidence that below-average rainfalls and above-average temperatures in the long term may highly likely depress agricultural productivity in Uganda [7].

Maize is not exceptional to escape impacts from droughts and temperature increases. It was reported that droughts could cause up to 80% maize yield loss and a temperature-increase to 27°C decreased maize production [2, 28]. However, to take better measures to protect maize from the adverse weather shocks, it is important to gauge a degree to which the crop production is drought-vulnerable in the first place. A recent study attempted to estimate the drought vulnerability of maize production in Uganda under a predetermined set of precipitation and temperature [2]. In this study, vulnerability is defined as the degree to which a system is susceptible to and unable to cope and recover from adverse effects of extreme weather events and climate change. The concept of vulnerability is specified as a function of three to project future vulnerability of maize yield: maize sensitivity, maize exposure to droughts and temperature increase, and adaptive capacity of maize and farmers.

In detail, first, sensitivity is defined as a reduction in maize yield due to drought and temperature increase. Second, exposure is described as magnitude, intensity and duration of drought and temperature increase on maize yield. Third, adaptive capacity is defined as flexibility or ability of the maize production system to adjust to drought and temperature increase and to cope with their consequences. In the study, adaptive capacity is represented with two proxies, % of poverty and % of literacy rate as a material and human asset,

respectively [2].

The overall result of the study indicated that the drought vulnerability of maize production was high or 0.6 (defined high if > 0.57) based on the 1960-2014 precipitation data. However, the drought vulnerability could be as high as 1.54 if the future temperature increased by 2.5°C. This level of vulnerability was over twice of 0.7 with a temperature change by 2.0°C. Among the three indices, the sensitivity defined as maize yield reduction noticeably increased from 1.16 to 2.0 with the temperature changes, whereas the exposure and adaptive capacity remained the same. At a geographical level, the vulnerability varied with latitudes of the maize production areas. The northern areas showed higher drought vulnerability compared to the southern areas. In the north, it ranged from 0.58 to 0.64 while in the south, the highest was 0.27. More importantly, the adaptive capacity decreased in the north while the vulnerability, exposure and sensitivity to droughts tended to increase in this area [2].

The study explains that this spatial disparity in drought vulnerability was probably due to multiple factors. First, a different precipitation pattern between the two regions may be an explanation: in the north of Uganda, precipitation is unimodal (April-October) with lower levels of rainfall while bimodal (March-May and September-November) in the south. In addition, the south has water sources to help enhance precipitation such as lakes Victoria, Albert and Edwards. Another important factor is a different socio-economic gap between the two regions. For instance, the poverty rate in the north was estimated 46.2%, considerably higher than 21.8% in the south. Generally, a high level of poverty limits access to key production inputs such as fertilizer, improved seed, and irrigation [2]. It may also limit access to financial services. Moreover, the literacy rate in the north ranged from 60% to 63% while markedly higher in the south from 63% to 75% with the national average 69.6% [2]. The lower literacy rate in the north may further limit access to key information on technical knowledge and skills to better cope with adverse weather events.

As a conclusion, this study suggests the adaptive capacity based on the two proxies (poverty and literacy) is the most important of the three indices to cope with droughts: the trajectory of climate change cannot be determined for the sensitivity and exposure whereas the adaptive capacity to climate shocks can be improved.

3.2. Adopter Characteristics of Drought-Tolerant Maize and Possible Determinants

According to a survey [13], maize farmers in Uganda could be categorized into three depending on their farming characteristics: commercial, limited cash input and no cash input (Table 2). The survey found over 60% of the maize farmers utilized no improved input at all and the maize yield in this category was substantially low compared to the other two.

Given that most maize farmers are smallholders who are

resource-constrained and subsistence-oriented, their decision to adopt improved maize such as DTM may well be influenced by perceived risks or uncertainties [22]. One of the most intuitive risks can be economic uncertainty. While farmer-saved local seed may cost none, improved seed including DTM can cost up to USD 3 per kg [12, 27]. When compensation of an additional cost to adopt DTM is uncertain, maize farmers unlikely consider adopting it and likely choose other options. However, a benefit-cost analysis with DTM in Uganda indicated DTM appeared economically viable compared to a local variety [27].

Table 2. Categories of maize farmers in Uganda.

Farmer Category	Number of Farmers (% of All Maize Farmers)	Average Size of Maize Farm	% of Produce Sold	Improved Input	Yield (tons/ha)
Commercial	170,000 (About 5%)	>5 ha	100%	Full package	>3.5
Limited cash input	1,200,000 (About 35%)	2-5 ha	50%	Limited fertilizer + improved seed	2.1 – 3.5
No cash input	2,100,000 (over 60%)	<2 ha	<50%	No fertilizer + improved seed	1.1 - 2.1

Reference [13].

This benefit-cost study estimated net benefits, costs and their ratios to analyze DTM cultivation in economic terms. In doing so, five DTM varieties that are widely cultivated across Uganda (the longe 4, 5, 7H, 10H and MM3) and one local variety were tested. The result indicates that the average net benefit of DTM was 140% higher than the local (USD 820 for the DTM and USD 342 for the local). Among the DTM varieties, the longe5 and 7H brought the highest net returns or USD 1030 and 919, respectively, under the dry spell. These were approximately three times higher than the local with USD 342. For the benefit-cost ratio, the DTM was 2.9 on average, whereas that of the local was 1.75 [27]. This study found the DTM generated higher economic benefits under the trial conditions including ploughing both manually and by ox, seeding rate of 10 kg/acre, weeding twice and fertilizer application. Although the result from one study should not be generalized, the benefit-cost appeared favorable for DTM in Uganda, suggesting economic terms are not the sole reason for the current low DTM adoption.

From the farmers' side, the DTM adoption process starts with them becoming aware of DTM existence as potential adopters [19, 20]. Then, the farmers who acquire information and understand the attributes of DTM make an adoption decision. When they decide to cultivate DTM as a trial, the seed must be physically available, accessible and affordable. With their DTM trial experiences, the farmers may continue or discontinue planting DTM. Finally, the DTM adopters may share information with other maize farmers and the cycle restarts [22, 23] (Fig. 1).

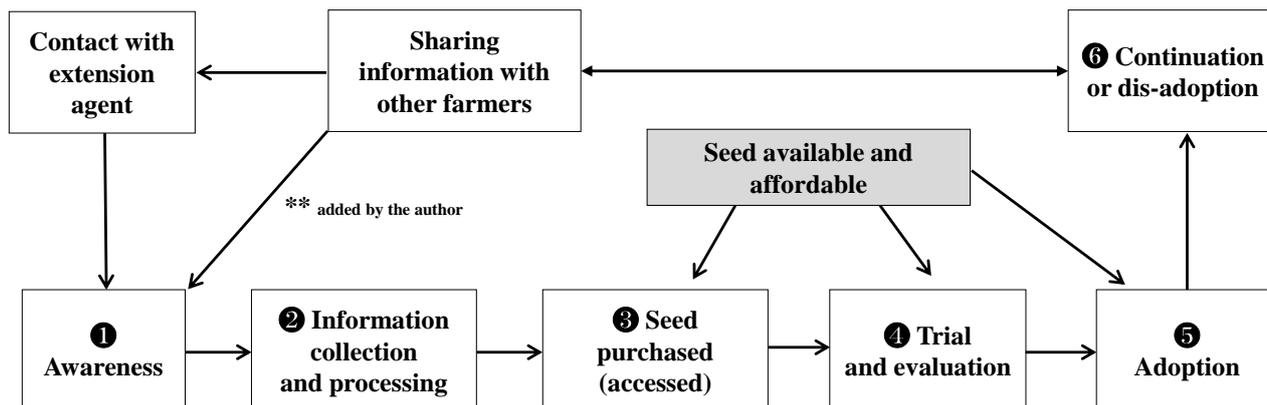


Fig. (1). Farmer adoption stages for improved seed adoption from [22, 23].

Table 3. Descriptive characteristics of drought-tolerant maize adopters and non-adopters.

Descriptive Characteristics of Adopters and Non-Adopters				
Category	Simtow <i>et al.</i> 2019 [23]	Mean difference	Kakuru 2019 [28]	P-value and χ^2
Household	Age of household head (year)	0.43 (ns)	Age of farmer (year)	0.000 (p)
	Education	0.23 (ns)	Education level (year)	0.000 (p)
	Household size (number)	0.64**	Farming experience (year)	0.000 (p)
Land	Landholding size (ha)	0.51**	Land owned (ha)	0.003 (p)
	Maize area (ha)	0.17***	Maize area (ha)	0.001 (p)
Wealth	Income to build savings (yes/no)	0.009***	Monthly income (UGx \$)	0.000 (p)
	Livestock herd (tropical livestock unit)	0.24*	Access to credit (yes/no)	71.21*** (χ^2)
Farming	Production input #	hired labor (0.15***), manure (0.08***), fertilizer (0.15***), pesticide (0.11***), fertilizer rate (7.15**), seed rate (-4.89***)	Fertilizer use (yes/no)	2.46 (χ^2 : ns)
			Self-sufficiency in maize production (yes/no)	5.41*** (χ^2)
	Maize yield (kg/ha)	212*	Maize produced (kg)	0.095 (p)

*p<0.1, ** p<0.05, *** p<0.01 #: hired labor (yes/no), manure (yes/no), chemical fertilizer(yes/no), pesticide (yes/no), fertilizer rate (kg/ha), seed rate (kg/ha), Seed rate use (kg/ha) §: Ugandan shilling

Table 4. Possible adoption determinants of drought-tolerant maize.

DTM Adoption Determinants						
Category	Simtow <i>et al.</i> 2019 [23]	Coefficient	Simtow <i>et al.</i> 2019 [22]	Coefficient [†]	Kakuru 2019 [28]	Coefficient
Awareness & information	Household size (number)	0.06***	Education (year)	0.010*	Education of farmer (year)	0.026 [†]
			Household size (number)	0.012*	Drought occurrence (number of times)	0.527**
	Information on new maize (dummy)	0.22**	Information source [‡]	Gov. (0.278**), electronic media (0.120*)	Awareness of DTM (yes/no)	0.371***
Accessibility	Income to build saving (yes/no)	0.96**	Income to build saving ¥¥	0.333***	Distance to seed source (km)	-0.011*
			Subsidy received (yes/no)	0.387***	Seed price (UGx §)	-0.001***

ns: not significant, *p<0.1, ** p<0.05, *** p<0.01 §: Ugandan shilling ¥: reference group: no info received ¥¥: reference group (insufficient, need borrowing) ¶: results based on the condition of unrestricted awareness-access-affordability

For the adoption process, some studies explored characteristics of DTM adopters and possible determinants in detail. The following section reviews these studies and their key findings are summarized in (Tables 3 and 4).

The first study analyzed 840 maize-growing households in 14 districts across the eastern, western, northern, and central regions of Uganda and observed differences in household characteristics between DTM adopters and non-adopters [23]. For an average household size, the adopters had a significantly

larger household (6.9) than the non-adopters (6.27). Also, the adopters owned a larger land (2.2ha) and livestock herd (1.29) than the non-adopters (1.7ha for land and 1.04 for livestock herd). Relatedly, the adopters dominated the top income category allowing 17% of them to save compared to 9% of the non-adopters. For the access to information, the adopters (53%) more likely had access to information than the non-adopters (37%), indicating that the adopters were more informed than the non-adopters. In terms of input use, the adopters more commonly used hired labor, manure, chemical fertilizer, and pesticide. For instance, 24% of the adopters applied fertilizer, while only 10% of the non-adopters applied it. In addition, the adopters applied a larger amount of fertilizer (14.01kg/ha) than the non-adopters (6.86kg/ha). The adopters also allocated a significantly larger plot to maize (0.64ha) than the non-adopters (0.47ha). The adopters reported a higher maize grain yield (1.7ton/ha) than the non-adopters (1.5ton/ha). However, the seed use rate was lower in the adopters (21.82kg/ha) than the non-adopters (26.71kg/ha). Overall, the sampled DTM adopters appeared to be better resource-endowed, had better access to information, cultivated more maize, applied more inputs, used less seed and harvested better yield.

Furthermore, the study identified possible determinants with significant coefficients by controlling other production factors in the sampled households. The adoption determinants identified included a larger household size, higher income, more information received on varieties and higher use of hired labor and manure [23].

A separate study with the same household data (yet 864 households) as the previous study was set to further predict potential DTM-adoption rates with specific conditions as well as to identify DTM adoption characteristics [22]. Although the results of the most socioeconomic characteristics were similar to the previous study as expected, some characteristics related to information exposure and seed accessibility were more detailed and informative. First, while the adopters were more exposed to information on new varieties, there was a difference in information sources: significantly more adopters (12%) received information from the government extension services compared to the non-adopters (2%). Yet, the major source of information for both groups (81% for the adopters and 76% for non-adopters) was a social membership such as cooperatives and farmer groups. Aside from the different characteristics in exposure to information, a large gap was observed in physical and economic access to seed between the two groups. The gap was 68.8% in physical access to seed and 86.8% in economic access to seed *i.e.* access to affordable seed. An additional observation that more adopters (12%) received free seed than the non-adopters (2%) probably contributed to the widened physical access gap to seed and the adopters' better-endowment and wealth-related factors likely help them make trips and purchase DTM seed [22].

Albeit, in a smaller scale than the previous two studies, this study similarly identified key characteristics of DTM adopters, adoption constraints and determinants [28]. The study examined 190 households (95 DTM adopting households and 95 non-adopting ones) in Kamuli (south-east) and Masindi (mid-west) districts. An adopter for the study was defined as a

farmer who grew DTM at least for two consecutive seasons and did not use recycled seed.

There were differences in socioeconomic characteristics between the two groups in age, income, education, land size, maize cultivation acreage and access to credit among others. In detail, the adopters tended to be older and more educated with higher income, better access to credit and larger farmland and maize cultivation area than the non-adopters. For input use, more adopters tended to use fertilizer (12%) than the non-adopters (1%), although the overall fertilizer use was limited in both groups. For awareness and information source, only 5.8% of the non-adopters were aware of the DTM and more of the adopters received relevant information from the government extension services and non-governmental organizations: 58% of the adopters received information from the two sources while 38% of the non-adopters did. In a further analysis with coefficients, key determinants of DTM adoption included a level of education, year of experience in maize farming, seed price, distance to seed source, awareness and frequency of drought occurrence [28]. The reason that drought occurrence frequency was included might be that 91% of the sample reported they experienced droughts at least twice in the last decade, thus could have suffered a reduced maize yield due to the droughts. And the sample households in these two districts identified a high seed price as a major barrier (57%) to DTM adoption followed by fertilizer requirement, lack of awareness and limited access to seed.

Overall, the three studies indicated that the DTM adopters appeared to be better endowed with production resources, be more informed, educated and experienced, have a larger household, use inputs more efficiently, earn higher income and harvest better yield. However, it was not empirically explained how these characteristics may relate to one another (for instance, causality) and what characteristics can weigh more for DTM adoption.

A large-scale study across six SSA countries (Ethiopia, Malawi, Tanzania, Uganda, Zambia, and Zimbabwe) examined determinants and constraints of DTM adoption [30]. The result averaged in the six countries showed that maize farmers were more likely to grow DTM if they highly valued grain yield, early maturity and drought tolerance. Similarly, the adopters were found to have more education, larger land, more exposure to information. The main barriers for DTM adoption included seed availability, information receipt, resource availability, seed price and seed attribute [30]. Those overall results drawn from the six countries appeared corresponding to the ones specifically identified in Uganda. It indicates other SSA countries might have similar DTM-adopter characteristics and adoption constraints.

3.3. Maize Attribute Preferences and Input Qualities for DTM Adoption

The previous studies indicated that awareness of DTM seemed influenced by the household's ability to access and understand DTM information while seed accessibility might be essentially a function of wealth-related factors. Given that most maize growers in Uganda are smallholders, scaling-up DTM adoption partially depends on making seed widely available

and affordable as well as relaxing the information bottleneck [22]. With this rationale, a study predicted potential DTM adoption rates under three conditions related to awareness, seed availability and accessibility: first condition-adoption conditional on exposure to DTM *i.e.* unrestricted awareness; second condition-adoption conditional on awareness and physically available seed *i.e.* unrestricted awareness-access; third condition-adoption conditional on awareness, physically available seed and affordable seed *i.e.* unrestricted awareness-access-affordability.

On the first condition, it was estimated that the DTM adoption in Uganda could have been up to 22% if the whole population had been aware of the DTM, instead of 14%, the sampled DTM adoption rate. On the second condition, the adoption rate could have increased to 30% if the seed had been physically accessible in addition to awareness. On the third condition, the adoption rate could have been up to 47% if the DTM seed was affordable in addition to awareness and availability. These predicted adoption gaps were 8%, 16% and 33% for each of the three conditions [22]. This suggests that it is feasible to scale up DTM adoption once a bottleneck in awareness, seed availability and seed affordability is relaxed. Yet, this result simultaneously implies that universal adoption of DTM in Uganda is highly unlikely even after the bottleneck is removed. This indicates that other obstacles need to be delivered for a wider DTM adoption.

One such obstacle might be competition with other non-DTMs with preferred attributes that are not currently incorporated in the DTM varieties [12]. In order to examine preferences of maize attributes, a study was conducted in Masindi and Iganga, the two main maize-producing areas in Uganda. Nine leading maize varieties were preference-tested, including four DTMs (longe 1, 4, 5, and 7H). Of the nine varieties, longe6H (non-DTM) was the most preferred (75%) on a hedonic scale followed by longe5 (69%). The key attributes for their popularity were relative early maturity, resistance to pest and disease and seed availability. As longe6H is non-DTM, its relative early maturity (125 days) may be attributed to the popularity with its ability to escape droughts. The importance of early maturity was also reflected in the farmer's willingness-to-pay: the farmers were willing to pay 56.5% more for early maturity. However, curiously, drought tolerance itself had no significant influence on their willingness-to-pay in this study [12]. Although longe5 has a shorter maturity (115 days) than longe6H, longe5 has a much lower yield (4-6 ton/ha) than longe6H (8 ton/ha). Additionally, longe5 is susceptible to northern corn leaf blight, while longe6H is resistant [12]. The overall result indicates that farmer preferences need to be considered in breeding DTM for further adoption, once again emphasizing a participatory breeding process.

In general, cultivating an improved variety is certainly more advantageous than an unimproved one. One of the advantages is the difference in their input elasticity, especially to fertilizer. Farmers in Uganda may well be aware of the positive relationship between fertilizer application and yield. Nevertheless, its application in maize production remains low with the nitrogen (N) as the main limiting component [31, 32].

A survey found the fertilizer application rate in maize in Uganda was far below the recommended rate (6 kg/ha for the surveyed application rate vs. 100 kg/ha for the recommended rate) and only 5% of the maize area received the recommended rate [13]. Low or lack of fertilizer application can prevent improved maize from fully expressing its potential. And the requirement of complementary fertilizer can discourage smallholders to adopt improved maize and it was indeed identified as a DTM adoption constraint [28].

Anecdotally, the low adoption of improved maize seed and fertilizer is partly due to low farmer confidence in their market quality. The government of Uganda in fact, recognizes the prevalence of counterfeit seed in the market across the country [25]. According to the Uganda National Seed Policy, 30-40% of the seed traded in the market was estimated counterfeit [6]. This is partly due to the unstable seed procurement system and weak public forces to regulate the counterfeit seed industry [25, 26]. Market quality of fertilizer is often questioned as well. Maize farmers as consumers do not observe their quality before using seed and fertilizer since both are experience goods. Therefore, maize farmer's ability and confidence to know about the market quality of seed and fertilizer influence their purchasing decision [32]. Thus, a supply situation of the key inputs in quality can influence DTM adoption.

To empirically investigate this input quality issue in Uganda, a study examined the market quality of fertilizer and improved maize seed and assessed whether the quality of the two could explain the current low take-up of both [32]. The study randomly obtained 369 samples of urea fertilizer as market-purchased fertilizer (market fertilizer hereinafter) and 30 samples of predetermined hybrid seed as market-purchased seed (market seed). For comparison, authentic urea fertilizer and hybrid seed were obtained directly from the fertilizer wholesalers and seed companies, respectively. The study however, did not mention if the hybrid maize seed was DTM. Nevertheless, the result offers an informative view of the current market quality of both.

First, the surveyed farmers were indeed aware of the substandard quality of the market fertilizer. On average, they expected the market fertilizer to contain 38% less N compared to the authentic and only 1% of the farmers believed the quality of the market fertilizer would be the same as the authentic. Secondly, the farmers were aware that using fertilizer increase maize yield, only depending on the fertilizer source. They expected maize yield 1.47 ton/ha without fertilizer, 2.53 ton/ha with the market fertilizer and 5.23 ton/ha with the authentic. This perception of the maize farmers was in line with the following test results.

The test of the market fertilizer found that it contained 31% less N on average (31.8% N per kg) than the authentic (46% N per kg). Moreover, about 10% of the market samples contained even less than 50% N of the authentic, and only 1% was short of less than 10% N of the authentic. While there was a substantial variation in fertilizer quality across the market samples, their prices were homogenous. For seed quality, the average quality of the market hybrid seed was similar to the quality of a mixture of 50% of the farmer seed and 50% of the authentic hybrid seed.

In production terms, maize yield loss due to the low quality of the market fertilizer was found largest with the authentic hybrid seed (65 kg/ha) followed by the market hybrid seed (57 kg/ha) and farmer seed (49 kg/ha). In economic terms, 81.6% of the market fertilizer was found not profitable with the market hybrid seed. On the contrary, 100% of the authentic fertilizer with the authentic hybrid seed was profitable. In detail, the utilization of both market fertilizer and hybrid seed resulted in a negative mean return rate or -12.2%. In contrast, the utilization of both authentic fertilizer and hybrid seed resulted in 51% of the mean return rate. However, when the market fertilizer was applied to farmer seed, the mean rate of return was positive or 6.8% as farmer seed costs none or little. In comparison, that of the authentic fertilizer with farmer seed was 54.2% [32]. Together, these results imply the adoption of the two technologies currently available in the local market appears simply unprofitable and farmers seem acting accordingly as a rational being in economic terms.

The result of this study offers three important observations [32]. First, the farmers were aware that the quality of the market fertilizer was inferior and that the fertilizer sources made differences in yield. Second, the prevalence of the low-quality inputs is highly likely in the current market of Uganda. Third, smallholder maize farmers may not adopt the improved seed and fertilizer due to negative or uncertain economic returns.

Suri (2009) also highlights that uncertainty in returns could be a high barrier to technology adoption: adoption may be low when returns are heterogeneous as well as low [33]. It is probable that the current maize input market of Uganda is characterized by an equilibrium of low-quality input, low-trust, and low-adoption [32]. Low quality of production input could come from multiple factors, including a weak regulation, adulteration, inappropriate handling, or storage. Circumstantial evidence suggests that adulteration by bulking fertilizer or dyeing seed to appear hybrid is not uncommon. Furthermore, the low and heterogeneous quality of the input is not correlated with its market price. This indicates that an important reference for market input quality is missing since a price is generally adjusted with quality [32]. This, in turn, highlights that the current market ambiguity needs to be cleared for effective DTM promotion.

4. DISCUSSION

Maize is an important food and cash crop for smallholders in Uganda and the current low productivity of the crop needs to be improved. One of the most effective means in doing so is active adoption of available technologies. Of the technologies, this study focused on DTM for enhanced productivity and reduced production risks under increasing temperatures and droughts.

The reviewed studies found distinct characteristics in DTM adopters and probable adoption constraints. The major constraints appear to include lack of awareness, limited seed availability and accessibility, complementary input requirement, existing DTM attributes and dubious market quality of seed and fertilizer. And the DTM adopters were observed to have a larger household, larger farmland, higher

income, better education, better access to information, more utilization of production input, longer farming experience and higher maize yield than the non-adopters. These results and observations are in line with other similar studies. For instance, Uaiene *et al.* (2009) concluded in their Mozambique study that households with higher education and access to agricultural advisory services, rural credit and membership of agricultural associations were more likely to adopt new agricultural technologies [15]. Kassie *et al.* (2011) also identified that farm size, years of education, membership in local farmers' organizations, and plot number were positively associated with improved groundnut adoption in Uganda [34]. On the other hand, lack of access to groundnut seed and distance to the main market were negatively associated with adoption. Also, this study identified adoption constraints including uneven availability of improved seeds, lack of development of market infrastructure, and poor access to information and agriculture extension services [34].

With the DTM adoption, the constraints and socioeconomic characteristics of adopters seem intertwined as a virtuous or vicious cycle. Larger households have advantages in available labor and exposure to information. This can contribute to higher awareness of DTM in the first place. Wealthier households can afford to be less risk-averse to purchase higher-priced DTM seed. In addition, they can utilize necessary complementary inputs such as fertilizer that likely maximizes DTM yield. Furthermore, these wealthier households with more education may better understand the received information and use it more effectively. Kassie *et al.* (2011) argue that education may be a proxy for access to information and the ability to understand the importance of new technology and relevant information. This may further widen an adoption gap between higher-income more-educated and lower-income less-educated households.

Similarly, larger farmland may indicate a household is more commercial-oriented thus more likely to use higher production input, pays more attention to relevant information, and becomes more informed for increased productivity. Larger land also allows the household to allocate a larger plot to DTM trial and/or cultivation. More experience in farming may suggest having more information of available technologies. Additionally, more experience means a household might have faced various production challenges, thus becoming more receptive to newly available technologies. Although these factors seem tightly connected, some of the factors can be successfully addressed with government interventions and public-private cooperation.

First, the seed must be readily and physically accessible. As identified in the reviewed studies, seed availability was one of the key attributes for an adoption decision and a distance to seed source was one of the important determinants [12, 25]. Therefore, the government needs to ensure that sufficient DTM seed is available at a local market and extension service. While it is true that the existing inadequate infrastructure for seed production, marketing and distribution in Uganda is not readily resolvable in the short run, DTM seed is unique in that the government, private seed industry and international projects have been successfully collaborating for improved maize seed.

Thus, the government can strengthen public-private-international cooperation for DTM seed production and distribution.

At the same time, the government should ensure to remove distribution bias with DTM seed. For instance, a seed distributor could sell DTM seed in certain areas where higher profits due to larger sales volumes, higher prices or lower transaction costs can be earned. A distribution bias also occurs if extension agents target specific maize farmers who are more likely to adopt DTM seed [22]. In this regard, the government needs to supervise the subsidized-DTM seed distribution and regulate the commercial DTM distributors' market behaviors.

The physically available DTM seed must be of genuine quality. Although the 85% seeds planted in Uganda are channeled through the informal system, a large portion of improved maize seed is regulated in the formal system. Nevertheless, the empirical studies as well as the government of Uganda indicate that the present market quality of improved maize seed is low due to counterfeit products. Therefore, strong regulations against counterfeits should be enforced to recover farmer confidence in the market seed and other complementary inputs such as fertilizer. Otherwise, the adoption of DTM will be limited and unsustainable.

Second, the economic accessibility to DTM seed can be improved for maize smallholders lacking cash and credit. Magruder (2018) notes that the provision of cash, credit and insurance appeared to motivate technology adoption for minority farmers [35]. An increase in the government subsidy or voucher helps lower the price barrier for eligible smallholders, whereas international aid programs may distribute a free package with DTM seed and fertilizer to the most vulnerable. In addition, free DTM seed for a trial provides both information and experience with DTM, which reduces risk-aversion of potential adopters. For the part of maize farmers in Uganda, they should come to terms with price differences in different types of seed such as the local, OP and hybrid [22]. The understanding of the price difference is necessary not to create dependency on the public aid for sustained DTM cultivation.

Third, lowering the information barrier is critical for smallholder maize farmers who are limited to information sources and education. The provision of easier and wider access to information increases awareness of DTM and complementary training courses certainly help smallholders better understand the received information and technical advice. Thus, the public institutions can play a key role in providing awareness campaigns and training since the extension services, farmer groups and NGOs were identified as the important sources of information. However, delivery of the information and training should be appropriate, direct, simplified and timely given the characteristics of the target farmers. Furthermore, these trained farmers can share their experiences and DTM information with other potential adopters who otherwise would not be informed of or interested in DTM. This information sharing will facilitate DTM adoption and help scale-up in the long term.

From a policy standpoint, the constraints need to be

collectively addressed from seed production and quality control to sustained cultivation of DTM since a variety of factors affects the adoption process. Although the task is overwhelming, this can be achieved by the Uganda government collaborating with international donors, multilateral organizations and private sectors. The key players can collaborate by supporting and more critically, aligning existing DTM-related programs to synergize them while launching new ones together to bridge the adoption gap.

CONCLUSION

Improved quality seed is one of the best renewable production resources and key to high productivity. Therefore, intensified utilization of such seed is essential to make transitions from subsistent to market-oriented and from food insecure to secure [6]. Uganda has been grappling with rural poverty and food insecurity and DTM can make a significant contribution to improving both. In this review, a broad range of DTM adoption constraints is identified from a household, market and national level. Nonetheless, DTM can be further adopted when the government takes more supportive measures and effective strategies for sustainable DTM uptake.

Finally, generalization of the findings in this study should be cautiously limited for two reasons: first, it is done with a single country; second, a systemic review could not be carried out due to insufficient literature available. However, as the overall result of the DTM adoption situation in Uganda appears similar to the one across the six SSA countries, it could provide helpful implications to promote DTM around this region as well.

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CONFLICT OF INTEREST

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