

# Assessing Drought Effects on Banana Production and On-Farm Coping Strategies by Farmers – A Study in the Cattle Corridor of Uganda

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## Research Article

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# Abstract

Drought is a major threat to banana production in Uganda, leading to large yield losses. This study documented drought effects on banana production and identified farmers' coping strategies to mitigate the impact of droughts. Interviews were conducted in eight districts, randomly selected from banana-growing districts in Uganda's cattle corridor, characterised by frequent droughts. Data were collected from 120 respondents/farms. Banana production in the study area was dominated by small-scale farmers, growing mostly a combination of cooking and dessert banana types. Among the 15 identified effects of drought stress on banana growth, reduced bunch weight, wilting and drying of leaves, reduced leaf production and reduced number of fingers and clusters were the most reported. 'Mpologoma' and 'FHIA 17' cultivars were reported as the most and least affected by drought stress, respectively. Although the cattle corridor is prone to recurrent droughts, the deployment of drought coping strategies was mostly low, with farmers using one to three strategies. A total of 12 drought mitigation practices were used across the cattle corridor, with mulching being the most common option. Irrigation was perceived as the most effective mitigation option though its deployment was limited by water scarcity and the high cost of water pumps. This study suggests the need for government support in drought stress mitigation practices and the development of drought-tolerant cultivars by breeders. Additionally, farmers need to prioritise preventive coping strategies like planting drought-tolerant cultivars, irrigation, mulching, and manure application and ensure the appropriate time of deployment of mitigation practices.

## 1. Introduction

Banana (*Musa* spp.) is a major food and cash crop worldwide, particularly in the tropical and subtropical regions. The crop has a global production of 116.8 million tons harvested from an area of 5.16 million ha (FAOSTAT 2019). The East and Central African subregion, including Uganda, Tanzania, Kenya, Burundi, Rwanda and the eastern part of the Democratic Republic of Congo is home to a unique group of bananas well-known as the East African Highland Bananas (EAHBs, *Musa* AAA genome). Moreover, this region is also considered to be a secondary centre of diversity for the EAHBs and plantains (AAB genome) (Simmonds 1966), with an annual production of 17.31 million tons cultivated on 1.7 million ha (FAOSTAT 2019). In Uganda, EAHBs are the main staple food for over 13 million people, with cultivation mostly concentrated in the central and southwestern regions (Bill and Melinda Gates Foundation 2014). The crop is grown either as a sole crop or intercrop with other perennial or annual crops, offering additional benefits to the ecosystem in addition to animal feed, fibre, and food (van Asten et al. 2015; Ocimati et al. 2018). Although EAHBs are an important staple and commercial crop to many Ugandans (Bagamba 2007), actual production remains low ( $< 30 \text{ t ha}^{-1} \text{ year}^{-1}$ ) compared with the potential yield ( $> 70 \text{ t ha}^{-1} \text{ year}^{-1}$ ) (van Asten et al. 2005) due to a combination of biotic and abiotic stresses.

Several studies in Uganda have reported on biotic stresses such as banana bacterial wilt (*Xanthomonas campestris* pv. *musacearum*) (Ocimati et al. 2014a), banana weevil (*Cosmopolites sordidus*) (Gold et al. 2004; Ocan et al. 2008) parasitic nematodes (*Pratylenchus coffeae* and *Radopholus similis*) (Speijer 1999), fusarium wilt (*Fusarium oxysporum* f.sp. *cubense* [FOC]) (Kangire et al. 2000) and black leaf

streak disease (*Mycosphaerella fijiensis*) (Barekye et al. 2009). Prominent abiotic stresses include low soil fertility (Wairegi et al. 2010) and drought (inadequate soil moisture) (van Asten et al. 2011a).

Drought is a serious constraint to banana production in Uganda, particularly in the cattle corridor where the country's largest banana production is based. With most of the farmers depending on seasonal rainfall patterns, there is an immediate effect of climate variability (manifesting as drought and unreliable rainfall) on crop production, food security, income, and livelihoods in general (NAPA 2007; Anwar et al. 2013). The National Environment Management Authority (NEMA) (2016) reported that Uganda's cattle corridor is vulnerable to climate change impacts such as floods, erratic rains, high temperatures and prolonged droughts. Consequently, the effects of drought on several sectors (including agriculture) within the region have attracted a number of studies (Nimusiima et al. 2013; Kilimani et al. 2015; Owoyesigire et al. 2016; Branch 2018). Twongyirwe et al. (2019) evaluated farmers' perceptions of how drought affects household food security, existing coping responses and their determinants. They found that households were most vulnerable to drought-induced food insecurity and hence access to financial services and other sources of livelihood may offer resilience to such drought effects. In another study by Mfitumukiza et al. (2017), large crop losses and damages per household due to drought were reported.

However, the above studies did not consider the impact of drought on banana production in isolation but rather on crop production in general. There are gaps in literature regarding the daunting effects of drought stress on banana production and yield. Numerous studies focussing on phenotypic and physiological changes of selected banana genotypes to drought stress (also termed as moisture stress) have been conducted, but most of these have been carried out on-station under controlled conditions (Bananuka et al. 1999), with few studies conducted in the field (Wairegi et al. 2010; Taulya et al. 2014; Uwimana et al. 2021). One of the field studies found that drought results in crop failure and reduced bunch yield (up to 65% losses) when the rainfall falls below 1,100 mm per year (van Asten et al. 2011a).

While several efforts have been made or are being undertaken to increase the resilience of bananas to drought conditions through research and agronomic or crop management (van Asten et al. 2011a; Nansamba et al. 2020), knowledge of how specific farmer-preferred cultivars respond to drought stress and holistic on-farm adaptive strategies by banana farmers is still limited. Drought effects, particularly on the production of locally grown banana cultivars, have not been systematically documented as a basis for use in banana improvement research. Understanding the impact of drought on different banana varieties and associated management measures by farmers is critical in managing drought effects on production across a scale and supporting the improvement of farmer coping practices. The purpose of this study was to assess the effects of drought on banana production and identify management strategies deployed by farmers. Specifically, the study aimed to i) document drought effects on all locally grown varieties in terms of impact on plant growth characteristics, yield and yield-related parameters, ii) establish the variability within the set of cultivars maintained by farmers i.e. identify which cultivars are highly sensitive, moderately tolerant, very tolerant or not affected by drought iii) identify on-farm coping practices employed by farmers for mitigating such adverse effects and iv) determine the specific purpose(s) for each coping strategy in mitigating drought effects on bananas.

## 2. Methodology

### 2.1 Study area and site selection

This study was conducted in eight districts lying within the cattle corridor of Uganda (Fig.1). The cattle corridor dominated mostly by pastoral rangelands covers an area of 84,000 stretching from North-east to South-west Uganda. In this predominantly semi-arid region, local communities rely mainly on rain-fed crop and livestock production for their livelihood (McGahey and Visser 2015; FAO 2019). The annual daily average minimum and maximum temperatures in the region are 21.5°C and 30°C, respectively (Nimusiima et al. 2018). The area receives poorly distributed annual rainfall of 1350mm (Mfitumukiza 2015), with two rainy seasons (March to June and late August to November-December) and two dry seasons (June-August and December-February) (Nimusiima et al. 2013; Ogwang et al. 2016). It is characterized by unpredictable climate change conditions such as unpredictable rainfall onsets and cessations, flooding, and recurrent and prolonged droughts (USAID 2011; Nimusiima et al. 2013).

According to Kajobe et al. (2016), Uganda has ten agro-ecological zones, five of which fall within the cattle corridor, including Southern drylands, Lake Victoria Crescent, Karamoja drylands, part of Mid Northern and part of Eastern agro-ecological zone. Among these five agro-ecological zones, the Southern drylands and Lake Victoria Crescent were purposively selected because they host the largest banana-based cropping systems. From the Southern dryland agro-ecological zone, four districts including Ibanda, Sembabule, Ntungamo and Isingiro were randomly selected. In the Lake Victoria Crescent agro-ecological zone, the randomly selected districts included Mubende, Luweero, Nakaseke and Kiboga. At district level, two sub-counties were randomly selected from a list of banana-growing sub-counties (Table 1).

### 2.2 Sampling, data collection and analysis

A total of 120 banana farms (i.e., 15 farms per district) were randomly selected with the assistance of District Agricultural and Extension Officers in the respective districts. Farms were only considered for selection if the plantation was at least 0.25 acres (with at least 100 banana plants) large and banana was grown as the main crop on that farm. It was assumed that this group of farmers had a better understanding and experience with the effects of drought on banana production, particularly drought effects on plant growth characteristics and yield, the response of different varieties as well as their coping strategies to mitigate adverse drought effects on-farm. Respondents participated in one-on-one interviews guided using a semi-structured questionnaire from which both quantitative and qualitative data were collected. The study was conducted towards the end of the long dry season of December to March 2018. Farm-level data were collected including, the banana plantation status, nature of the cropping system, drought stress effects on plant growth characteristics and farmers' on-farm coping strategies for mitigating drought effects on banana production.

Regarding plantation status, the interviewer recorded the plantation size, plantation management (poorly- or well-managed), plantation age, and banana cultivars grown. Plantations were considered 'well-

managed' if the farmer carried out basic agronomic management practices like mulching, water conservation, weeding, and pruning, while 'poorly-managed' plantations were neither mulched nor weeded at the time of visiting. The plantation age was captured and later grouped into six categories for further analysis. A list of banana varieties grown at each farm was recorded and coded for analysis. Cultivar names varied depending on the local language in that region but were reconciled using banana variety lists developed by Karamura et al. (2012), Marimo et al. (2019) and an agronomy extension training guide prepared by the National Banana Research Programme of the National Agricultural Research Organization (NARO) Uganda (NARO 2019). Following the classification of Karamura (1998), all grown cultivars were then categorised into four groups based on the use of their end products i.e., cooking, dessert, beer/juice, and roasting bananas. Lastly, farmers provided the key reasons for cultivar selection.

In the case of the nature of the cropping system, two options including monocropping (only bananas) and intercropping (banana [main crop] + other crops) systems were considered. Reasons for practicing these two cropping systems were then captured and in case of intercropping, the crops grown with bananas were identified.

The respondents were then probed to describe the effects and symptoms (in terms of changes in plant morphological growth characteristics) of drought stress manifested by sensitive cultivars and the scores for the different symptoms were later coded for analysis. Based on their experience and careful observation, farmers were then required to report the reaction of each cultivar (only those cultivars they cultivated) to drought stress using a four-point rating scale i.e. 3= highly sensitive, 2= moderately tolerant, 1= very tolerant and 0= no effect at all. Interviewers confirmed these effects by observing the plants since these interviews were conducted in farmers' fields. The most popular cultivars (i.e. grown by at least twenty farmers) were then ranked from most to least affected by drought using a weighted average index (WAI) adopted from Ndamani et al. (2016).

$$WAI = \frac{F_s \times 3 + F_m \times 2 + F_t \times 1 + F_n \times 0}{N}$$

Where  $F_s$  = frequency of responses with highly sensitive,  $F_m$  = frequency of responses with moderately tolerant,  $F_t$  = frequency of responses with very tolerant,  $F_n$  = frequency of responses with no drought stress effect response and  $N$  = total number of respondents growing a given cultivar (out of the total 120)

To determine on-farm coping strategies for mitigating adverse drought stress effects on bananas, farmers were asked about their deployment of different agronomic and crop management practices. These practices included mulching, irrigation, intercropping with trees/ shrubs, weeding, reduced leaf harvesting, construction of trenches or contour bands trenches within the plantations, manure application and others, if any. Depending on the number of interventions deployed, each respondent's extent of deployment of such on-farm drought coping practices was determined against a four-point rating scale as no practice (0 coping strategies), low (1-3 strategies), medium (4-6 strategies) and high practice (more

than 6 strategies). Respondents were also deliberately probed to specify the purpose of each intervention in mitigating drought effects on banana production and the time of deployment of each coping strategy.

The study data were analysed using the STATA 17 edition to derive inferential and descriptive statistics. Graphs were then generated in Microsoft Excel 2016 software using the data analysis from STATA 17. Pearson's product moment coefficient of correlation was used to determine the association between the focus and explanatory variables.

## 3 Results And Discussion

### 3.1 Characteristics of banana plantations

The banana plantations assessed varied in size, age, management, cultivars, cropping system, among others (Table 2). Most of the respondents were small- (57.5%) and medium-scale farmers (21.7%), with an average plantation size of 4.36 acres. All selected fields were more than one year old, with those ranging between 1 to 5 (33.3%) and above 20 years (29.2%) forming the majority. Banana fields that are 30 to 50 years old have been reported to be common in the East and Central African region (Bekunda, 1999; Gold et al., 1999). Over 85% of respondents had well-managed plantations while 14.2% had poorly managed farms. Farmers cultivated a total of 54 banana varieties (mean= 8.4, minimum=2 and maximum=19 cultivars), mostly comprising of a combination of cooking and dessert use types (29.2%), followed by cooking, dessert and roasting types combined (21.7%). Only 13.3% of the farmers cultivated one use type bananas, specifically the cooking type, while 13.3% cultivated all the four use groups. Growing mixed banana varieties is regarded as important because each variety has a unique set of production and consumption attributes, which vary in terms of composition and levels (Edmeades et al. 2008; Akankwasa et al. 2013; Akankwasa et al. 2020). For instance, the grown banana varieties have different levels of tolerance to adverse climatic conditions such as prolonged drought and thus provide farmers with an opportunity to diversify against risks.

Among the four banana types grown, the cooking banana cultivars comprised the majority (Fig. 2), with each respondent growing at least one variety. Across the two agro-ecological zones, the top five cooking type cultivars were all EAHB types (*Musa* AAA genome) and included 'Mbwazirume', 'Kibuzi', 'Nakitembe', 'Mpologoma' and 'Nakabululu'. 'Sukali Ndizi' (AAB genome) and 'Bogoya' (AAA genome) were the most prominent dessert banana varieties (Table 3). However, the proportions of farmers in the southern drylands districts growing 'Mbwazirume', 'Kibuzi' and 'Bogoya' were significantly higher than those in Lake Victoria crescent districts (Table 4). 'Mbwazirume' was the most grown local cultivar because of its desirable consumer attributes, including good taste, soft food, and good flavour (Akankwasa et al. 2013; Akankwasa et al. 2020). 'Mbwazirume' is also often used as a reference cultivar in the banana breeding programme at NARO-Uganda (Nowankunda et al. 2015; Tumuhimbise et al. 2018, 2019). Farmers attributed their possession of fewer dessert and beer/juice types to destruction by fusarium wilt (caused by fungus *Fusarium oxysporum* f. sp. *cubense*), a soilborne disease. Dessert variety 'Bogoya' (syn. 'Gros Michel') and beer type 'Kayinja' (syn. Pisang Awak) are generally susceptible to *Foc* (Pegg et al. 2019).

Consequently, the few stands of dessert, beer and roasting bananas are planted mainly for home consumption with surplus sold in the local market.

Big bunch size was the main reason (55% of the respondents) for selecting specific banana cultivars, distantly followed by tolerance to drought stress (15%). Large bunch size has been reported as a key factor for selecting a specific variety because big bunches or fingers fetch a higher price in the market than their smaller-sized counterparts (Akankwasa et al. 2013; Marimo et al. 2019). However, similar to Bagamba et al. (2010), farmers also reported banana market prices to depend on the season. During the rainy season, the farm-gate price for bananas is low due to the high supply compared to the higher price offered during the dry season when the supply is low. In addition, farmers reported the availability of planting materials (from their old plantations, neighbours or improved varieties from banana breeders), resistance to pests and diseases, desirable taste and the cultivar's ability to thrive and yield even in low fertility soils as reasons for selecting cultivars. Similar observations have been reported in banana systems of Democratic Republic of Congo, Rwanda, and Burundi (Ocimati et al. 2013, 2014b, 2016).

## **3.2 Nature of cropping system**

More than half of the respondents (62.5%) had an intercropping system, whereas 37.5% reported a monocropping system. Farmers with an intercropping system had plantations with banana as the main crop and at least two other crop or tree species (Table 5). 86.1% of those respondents with an intercropping system grew trees/shrubs within or at the edges of their plantations, purposefully to provide stakes (for supporting big banana bunches from toppling or snapping), wood and food (from the edible fruits) and shade to their banana plants during very hot and sunny days (Table 5). Legume intercrops (43%), mainly with beans and peas accounted for the next dominant intercrop species. Banana intercropping with crops such as coffee (van Asten et al. 2011b) and beans (Bagamba et al. 1998) has been a common practice among Ugandan farmers over the years as a strategy to maximize crop production, increase family incomes, reduce pest and disease prevalence, improve soil fertility (leaf droppings act as organic mulch) and structure and increase resilience to adverse weather conditions such as drought (van Asten et al. 2015; Gambart et al. 2020). Farmers with an intercropping system also pointed out the need to diversify their diets to boost their intake of required nutrients which are low or lacking in bananas (Ekesa et al. 2013). On the other hand, banana growers with a monocropping system stated avoidance of competition for resources (light, soil nutrients, water) among intercrops and reducing banana shade effects on shorter crops as reasons for their choice. Moreover, intercropping is time-consuming and labour intensive, thereby adding to costs of operations such as weeding. Similar observations have been reported within the study region by Gambart et al. (2020).

## **3.3 Perceived and observed drought stress effects on banana growth characteristics**

Fig. 3 shows the observed effects of drought stress on the morphological characteristics of field-grown bananas. Drought effects observed and reported by farmers included reduced bunch weight (Fig. 3b; 90% of farmers), wilting and drying of leaves (Fig. 3a; 73%) and reduced leaf formation (63%) as the most prominent effects of drought stress across all grown banana cultivars (Fig. 4). Similarly, a reduction in bunch weight was reported by van Asten et al. (2011a) which may partly be attributed to a decline in the plant's photosynthetic capacity and rate (Flexas and Medrano 2002). However, farmers reported late exposure to drought (after bunch formation) not to affect bunch yield despite causing complete wilting and drying of leaves (Fig. 3a).

On drought-sensitive cultivars, additional drought effects reported included stunted growth (Fig. 3c), reduced size and number of fingers and/or clusters (Fig. 3d), drying and snapping of the pseudostem (Fig. 3e), halted or reduced sucker production, delayed flowering and bunch formation, longer bunch filling duration, reduced pseudostem size, and rapid leaf senescence. Interestingly, study respondents also reported some cultivar-specific drought stress symptoms. For instance, strangled birth was manifested by only two cultivars: 'Mpologoma' and 'Nakyatengu' (Fig. 3f). 'Mpologoma' was the only cultivar that displayed leaf petiole rosette formation (Fig. 3g) and abortion of the inflorescence, which occurs particularly during prolonged dry periods (Fig. 3h). The disintegration of the pseudostem was only observed in cultivars 'Kibuzi' and 'Entaragaza'.

These observations confirm some of the adverse effects of drought on banana growth that have been reported in previous field studies. For instance, Ravi and Uma (2011) reported drought-susceptible *Musa acuminata* diploids to produce fewer hands, ill-filled fruits and to experience bunch choking. Similarly, delays in phenological processes like flower development and increased fruit filling duration due to limiting soil water have been reported (Turner et al. 2007; Taulya et al. 2014).

Table 6 shows the most popularly grown banana cultivars (grown by at least 20 farmers) and their respective responses to drought stress as perceived by the study respondents based on the estimates of the WAI estimates. The larger the WAI value, the higher the impact of drought stress on a given cultivar. The cooking type cultivar 'Mpologoma' was reported as the most adversely impacted by drought stress (WAI=2.94), whereas 'FHIA 17', an exotic improved dessert hybrid, was ranked as the least affected (WAI=0.90). Farmers partly attributed the high sensitivity of 'Mpologoma' to drought stress to a high transpiration rate through the leaves and pseudostems (formed by tightly overlapping leaf sheaths). Although water is mainly lost from the banana plant through the leaf stomata by transpiration (Liu et al., 2008), part of it is also lost from the fleshy pseudostems. Compared to moderately tolerant cultivars like 'Nakabululu', 'Mpologoma' has very thin leaf sheaths (Fig. 5a) through which water is easily lost, thereby resulting in quicker desiccation, weakening, and snapping of the pseudostem during drought conditions.

On the other hand, cultivars like 'Nakabululu' have thicker leaf sheaths (Fig. 5b) which minimise the loss of water, hence their moderate tolerance to drought stress. However, it was interesting to note from farmers that 'Mpologoma' recovers much faster than other cultivars when drought conditions cease. On the other hand, 'FHIA 17' might have inherited its high tolerance to drought stress from one of its parent

cultivars, 'Gros Michel', locally known as 'Bogoya' (Van den Bergh et al. 2020). According to the WAI value in Table 6, 'Bogoya' was reported to be moderately tolerant to drought.

Considering the top five most grown cultivars, 'Kibuzi' was reported as the most affected by drought (WAI=2.07), followed by 'Nakitembe' (WAI=1.94). However, a significantly higher number of respondents in the Lake Victoria Crescent region reported both 'Kibuzi' and 'Nakitembe' to be moderately tolerant to drought stress than those in the Southern Drylands zone (Table 7).

### **3.4 On-farm coping strategies to mitigate drought stress effects on banana**

A total of 12 on-farm coping strategies were reported for minimising the daunting effects of drought on banana production (Fig. 6). Each practice was deployed for a specific purpose and time of deployment (Table 8). The five most deployed practices were mulching (56%), planting of mixed cultivars (35%), construction of water retention trenches or contour bands (23%), manure application (11%) and reduced leaf harvesting (18%). Some of these strategies such as mulching, application of manure and construction of water retention trenches form basic plantation management and soil-water conservation practices by Ugandan banana farmers (NARO 2019). Common mulch types used by farmers included residues from banana plants such as fresh or dry leaves and pseudostems, grass (e.g., spear grass, elephant grass), residues of other crops and dried weeds. Such organic mulch options were also reported by Bekunda (1999). Application of manure or fertilisers, especially potassium, ensures a healthy banana plant (Smithson et al. 2001; Zhang et al. 2020) that can withstand moisture stress, thereby masking the drought effects on plant growth (Taulya 2013; Panelo and Diza 2017). Farmers reported the application of organic fertilizers, particularly farm manures, as desirable but were constrained by its insufficient supply and high cost except those who reared livestock e.g., cows, goats and chickens. Other drought coping options deployed by respondents included irrigation, weeding, staking of weak plants (particularly for late season drought), tying of disintegrated pseudostems with banana fibres, intercropping with trees and cover crops, heaping of soil around exposed plant roots and sucker removal (they leave three to four plants per mat) (Fig. 7). Even though mulching was the most used coping practice (55.8%), many of the farmers (81.7%) pointed out irrigation as the most effective measure to mitigate drought effects on banana production.

Farmers reported several drought coping strategies, some of which are already documented in literature and others not (Fig. 6). However, farm-level use of drought coping strategies was predominantly low (72%), with most of the farmers deploying one to three drought coping strategies. Only 4% of the farmers used four to six practices (medium practice) while none of the farmers used more than six practices (high practice) to mitigate drought effects on their bananas. 24% of farmers did not deploy any of the drought coping strategies.

Farmers' management of climate change-related conditions such as drought is often influenced by prevailing climatic, economic and social factors (Shrestha et al. 2017). Rural communities are often resource limited and hence lack the means to combat the adverse effects of climate change (Mardy et al. 2018). In this study, farmers who did not practice any or a few on-farm drought coping strategies attributed their failure to the high cost of inputs e.g. water and mulch, water scarcity (there is not even enough water for home consumption), limited time and old age. Drought coping practices such as weeding, sourcing of mulch and mulching, collecting water from long distances for irrigation require a considerable amount of physical labour, which farmers lack and are hence limited in their capability to partake in such drought management activities. Moreover, their lack of monetary resources hinders them from sourcing for external labour. Limited access and high cost of irrigation equipment were also mentioned as hindrances for irrigation during dry periods. This confirms previous findings by Kabunga et al. (2012). Therefore, there is a need for intervention by development practitioners, particularly the government e.g., through subsidising agricultural equipment such as irrigation pumps.

### **3.5 Correlation between the characteristics of the farms and the extent of deployment of coping strategies**

The association between the extent of deployment of drought coping practices (focus variable) and two farm characteristics, plantation size and age, as explanatory variables were determined. Pearson's product-moment correlation coefficient ( $r$ ) indicated negative associations between the extent of deployment of drought strategies and the two explanatory variables, i.e.,  $r$  values -0.126 and -0.008 for plantation age and size, respectively. The negative association between the extent of deploying coping strategies and plantation size could be a reflection of resource limitation to deploy drought mitigation practices that are mostly costly on larger farms. The bigger the banana plantation, the more demanding and expensive it is to access drought management requirements such as hired labour, mulch, manure, irrigation water and equipment.

## **4. Conclusion**

This study has shown that the banana production systems in the cattle corridor of Uganda are severely threatened by drought. The intensity of drought effects on banana production varied with the cultivar and plant growth stage. Reduced bunch size, wilting and drying of leaves, reduced leaf formation, reduced size and number of fingers and clusters, stunted growth, drying and snapping of the pseudostem, halted or reduced sucker production, delayed flowering and bunch formation, longer bunch filling duration, reduced pseudostem size, and rapid leaf senescence are common drought effects on banana in the region. Cultivar-specific drought effects included strangled birth, abortion of the inflorescence, formation of petiole rosette and disintegration of the pseudostem. 'Mpologoma', a popular landrace cultivar for its large bunch size and high market price, ranked as the most affected cultivar, while 'FHIA 17', an exotic hybrid, was the most drought-tolerant cultivar.

To mitigate adverse drought effects, banana farmers in the Ugandan cattle corridor deploy different coping practices such as mulching, planting mixed cultivars, construction of water retention trenches or contour bands, reduced leaf harvesting, manure application, irrigation, weeding and staking of weak plants. Additional practices included tying of disintegrated pseudostems with banana fibres, intercropping with trees and cover crops, heaping soil around exposed plant roots, and removal of excess suckers. Mulching was the most practiced, while irrigation though among the least applied practices, was considered as the most effective for reducing drought effects on banana production.

Despite the importance of the above measures in mitigation of drought effects on-farm, the extent of their deployment was still limited by a shortage of resources (monetary, human, and physical resources). Deploying of some the measures will require government and policy interventions in terms of providing logistical support to farmers and subsidies. The development of drought-tolerant cultivars that require much less water for optimal growth needs to be explored by banana breeding programmes. Moreover, some of the popular cultivars that have been reported as tolerant to drought stress should be considered for use in such banana crossbreeding research. Given the nature of climate change-related phenomena like unpredictable withdrawal of rains and prolonged droughts, farmers need to prioritise preventive coping initiatives such as planting drought-tolerant cultivars, mulching (all year round) and manure application which protect plants against potential adverse drought effects rather than curative strategies. Moreover, such preventive strategies should be deployed at planting or before the onset of drought instead of adopting these practices during drought conditions or after the damage has already been caused.

## Declarations

**Author contributions statement:** Ms. Nansamba, Drs; Sibiya, Tumuhimbise, Karamura and Karamura contributed to the conception and design of this study. Ms. Nansamba carried out data collection and drafted the manuscript. Ms. Nansamba and Dr Kikulwe performed data analysis and interpretation. All authors provided critical revision of intellectual content and gave approval of final version for submission.

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**Data availability:** The data sets generated during and/ or analysed during the current study are available from the corresponding author on reasonable request.

**Materials availability:** Not applicable

**Code availability:** Not applicable

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## Tables

**Table 1** The location of sampled banana farms in the cattle corridor of Uganda

Agro-ecological zone	District selected	Sub-county visited
Southern Drylands	Ibanda	Igorora town council, Kijongo
	Sembabule	Mateete, Rwebitakuri
	Ntungamo	Rubaare, Ruhaama
	Isingiro	Masha, Birere
Lake Victoria crescent	Mubende	Bukuya, Makokoto
	Luweero	Bamunanika, Makulibita
	Nakaseke	Kasagga, Nakaseke
	Kiboga	Lwamata, Kibigga

**Table 2** Characteristics of banana plantations owned by respondents in the eight study districts located in the cattle corridor of Uganda

<b>Category</b>	<b>Proportion of respondents (%)</b>
Plantation size (acres)	
Small (0.25 – 2.5)	57.5
Medium (2.6 – 5.0)	21.7
Large (greater than 5.0)	20.8
Plantation age (scale score: 1-6)	
Less than 1 year	-
1-5 years	33.3
6-10 years	19.2
11-15 years	10.0
16-20 years	8.3
Above 20 years	29.2
Management level	
Well managed	85.8
Poorly managed	14.2
Banana types & combinations grown	
Cooking bananas only	13.3
Dessert bananas only	-
Beer/Juice bananas only	-
Roasting bananas only	-
Cooking & Dessert bananas	29.2
Cooking & Beer/Juice bananas	2.5
Cooking & Roasting bananas	3.3
Dessert & Beer/Juice bananas	-
Dessert & Roasting bananas	-
Beer/Juice & Roasting bananas	-
Cooking, Dessert & Beer/Juice bananas	15.8
Cooking, Dessert & Roasting bananas	21.7
Cooking, Beer/Juice & Roasting bananas	0.8
Dessert, Beer/Juice & Roasting bananas	-

All four banana types	13.3
Main reason for cultivar selection	
Big bunch size	55.0
Tolerance to drought stress	15.0
Pest and disease resistance	8.3
Availability of planting materials	5.0
Fast maturity	5.0
Desirable taste	5.0
Others	6.7
Cropping system	
Monocropping (only bananas)	37.5
Intercropping (bananas + other crops)	62.5

**Table 3** Local names and synonyms of banana cultivars grown by farmers in the eight study districts located in the cattle corridor of Uganda

<b>Local cultivar name</b>	<b>Synonym(s)</b>	<b>Banana type</b>	<b>Genome group</b>	<b>Proportion of respondents growing cultivar (%)</b>
Mbwazirume	-	Cooking	AAA	65.8
Kibuzi	-	Cooking	AAA	61.7
Nakitembe	Entaragaza	Cooking	AAA	57.5
Mpologoma	Bukadefu	Cooking	AAA	52.5
Nakabululu	Embururu	Cooking	AAA	52.5
Musakala	Enshakara, Rwamugongo	Cooking	AAA	40.0
Enyeru	Nabusa, Enyanshenyi, Enshenyi	Cooking	AAA	35.0
Muvubo	Mujuba, Mayovu	Cooking	AAA	32.5
Ndyabalangira	Enzirabushera	Cooking	AAA	27.5
Kisansa	-	Cooking	AAA	25.8
Enzirabahima	Entukura, Muziranyama	Cooking	AAA	23.3
Kivuuvu	-	Cooking	ABB	21.7
Nakinyika	Enjuuma	Cooking	AAA	20.8
Enjagata	Nandigobe	Cooking	AAA	18.3
Nfuuka	Ntiika, Enfuuka	Cooking	AAA	16.7
Butobe	Butoobe	Cooking	AAA	16.7
Nakyatengu	Ekitetengwa, Kitiika	Cooking	AAA	10.8
Atwalira	-	Cooking	AAA	10.0
FHIA 25	-	Cooking	AAB	9.2
Siira	-	Cooking	AAA	9.2
Namwezi	Kasa	Cooking	AAA	8.3
M9	Kiwangaazi, Kabana 6H	Cooking	AAA	7.5
Katwalo	Njoogabakazi, Kasenga, Kabucuragye, Entanzinduka	Cooking	AAA	7.5
Lwaddungu	-	Cooking	AAA	5.0
Nakamaali	Nakamali	Cooking	AAA	2.5
M2	Kabana 7H	Cooking	AAA	1.7

Namunwe	-	Cooking	AAA	1.7
Mukubakonde	Mukubyakonde	Cooking	AAA	1.7
Lumenyamagaali	-	Cooking	AAA	1.7
Lusumba	-	Cooking	AAA	1.7
Enyaruyonga	-	Cooking	AAA	1.7
M19	NAROBan1	Cooking	AAA	0.8
M20	NAROBan2	Cooking	AAA	0.8
M25	NAROBan3	Cooking	AAA	0.8
M27	NAROBan4	Cooking	AAA	0.8
Nakawere	-	Cooking	AAA	0.8
Nalugolima	-	Cooking	AAA	0.8
Nambi	-	Cooking	AAA	0.8
Mukazimugumba	-	Cooking	AAA	0.8
Lwakizita	-	Cooking	AAA	0.8
Enkunku	Bukunku, Makunku	Cooking	AAA	0.8
Namulondo	-	Cooking	AAA	0.8
Enyamanyamunyo	-	Cooking	AAA	0.8
Lwasa	-	Cooking	AAA	0.8
Gonja	Plantain	Roasting	ABB	40.0
Sukali Ndizi	Kabalagala, Apple banana	Dessert	AAB	61.7
Bogoya	Mbogoya, Gros Michel	Dessert	AAA	58.3
FHIA 17	Kabana 3H	Dessert	AAAA	24.2
Yangambi-KM5	Mufunyankobe	Dessert	AAB	9.2
FHIA 23	Kabana 4H	Dessert	AAAA	3.3
Kayinja	Musa	Beer /juice	ABB	20.8
Mbidde	Kabula, Enyarukira, Embiire	Beer /juice	AAA	15.8
Kisubi	-	Beer /juice	AB	3.3
Kibiddebidde	Kibidde	Beer	AAA	1.7

**Table 4** Proportion of farmers growing the five most popular banana cultivars in the two agro-ecological zones

Cultivar	Agro-ecological zone (%)		Chi square value
	Lake Victoria Crescent	Southern Drylands	
Mbwazirume	55.0	76.8	6.260** (0.012)
Kibuzi	40.0	83.3	23.831*** (0.000)
Sukali Ndizi	61.7	60.0	0.035 (0.852)
Bogoya	48.3	68.3	4.931** (0.026)
Nakitembe	60.0	53.3	0.543 (0.461)

\*\*\* $p < 0.01$ ; \*\* $p < 0.05$ ; \* $p < 0.1$ ; values in parenthesis are  $p$  values

**Table 5** Other crops grown in association with bananas by study respondents

Intercrop category	Specific crops grown	Proportion of respondents growing intercrop (%)
Trees /shrubs	<p><b><u>Tree crops</u></b></p> <p>Mango, avocado, jackfruit, orange, guava, coffee, pawpaw, java plum</p> <p><b><u>Wood or fodder trees</u></b></p> <p><i>Ficus natalensis, Albizia coriaria, Maesopsis eminii, Swietenia mahagoni</i> (mahogany)</p>	86.1
Legumes	Beans, cowpeas	43.1
Tubers	Cassava, sweet potatoes, yams	35.3
Vegetables	Eggplants, bitter berries, tomatoes, cabbage	19.6
Cucurbits	Pumpkins, bottle brush, calabash	5.9
Cereals	Maize	11.8
<b><u>Others</u></b>		
Fruits	Pineapples, passion fruit	17.6
Spices	Mint, lemon grass, rosemary, ginger	
Medicinal plants	<i>Aloe vera</i>	
Peanuts	Groundnut	
Grasses	Sugarcane, elephant grass	

**Table 6** Ranking of the most popular banana cultivars based on their response to drought stress as perceived by the study respondents (from most to least affected by drought)

Local cultivar name	Number of respondents reporting cultivar response to drought stress					WAI	Rank
	Frequency (n=120)	Highly sensitive	Moderately tolerant	Very tolerant	No effect		
Mpologoma	63	60	2	1	0	2.94	1
Kisansa	31	11	18	2	0	2.29	2
Enjagata	22	6	16	0	0	2.27	3
Musakala	48	13	33	2	0	2.23	4
Gonja	48	20	19	9	0	2.23	4
Ndyabalangira	33	8	22	3	0	2.15	6
Enzirabahima	28	10	12	6	0	2.14	7
Muvubo	39	6	31	2	0	2.10	8
Kibuzi	74	17	45	12	0	2.07	9
Butobe	20	5	9	6	0	1.95	10
Nakitembe	69	7	51	11	0	1.94	11
Mbwazirume	79	9	54	16	0	1.91	12
Nfuuka	20	1	16	3	0	1.90	13
Bogoya	70	13	30	27	0	1.80	14
Nakinyika	25	2	14	9	0	1.72	15
Enyeru	42	3	20	19	0	1.62	16
Nakabululu	63	3	25	35	0	1.49	17
Sukali Ndizi	74	1	29	44	0	1.42	18
Kayinja	25	0	9	16	0	1.36	19
Kivuuvu	26	0	10	15	1	1.35	20
FHIA 17	29	1	4	15	11	0.90	21

WAI denotes Weighted Average Index

**Table 7** Respondents' perceptions of the response of the five most grown banana cultivars to drought stress across the two selected agro-ecological zones

Cultivar	Drought sensitivity level	Agro-ecological zone (%)		
		Lake Victoria Crescent	Southern Drylands	Chi-square value
Mbwazirume	1	18.2	21.7	4.50 (0.105)
	2	78.8	60.9	
	3	3.0	17.4	
Kibuzi	1	23.1	16.0	7.80** (0.02)
	2	73.1	52.0	
	3	3.8	32.0	
Sukali Ndizi	1	51.3	66.7	2.43 (0.297)
	2	46.0	33.3	
	3	2.7	0.0	
Bogoya	1	27.6	46.3	3.348 (0.187)
	2	55.2	34.2	
	3	17.2	19.5	
Nakitembe	1	16.7	12.4	4.71* (0.095)
	2	80.5	68.8	
	3	2.8	18.8	

\*\*\*p < 0.01; \*\*p < 0.05; \*p < 0.1; values in parenthesis are *p* values

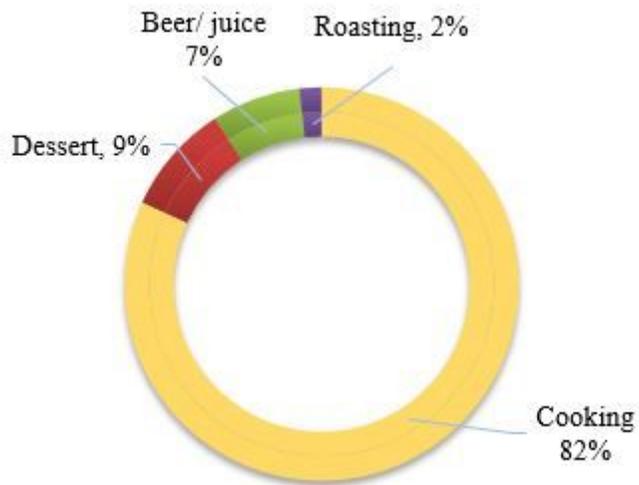
Cultivar drought sensitivity levels: 1- very tolerant; 2-moderately tolerant; 3-highly sensitive

**Table 8** Purpose and time of deployment of on-farm drought coping strategies by study respondents

<b>Drought coping practice</b>	<b>Purpose of intervention</b>	<b>Time of deployment</b>
Mulching	Preserving soil moisture by reducing evaporation	Throughout the growing season; during the drought period
Planting mixed cultivars	Diversify risk (due to drought effects) from a single cultivar	At planting
Irrigation	Replenish lost or used soil moisture	During the drought period
Intercropping	Tall trees or shrubs provide shade to bananas, especially on very hot days  Short trees, shrubs and cover crops serve as soil cover	Any time during the growing season
Reduced leaf harvesting	Ensure plants have adequate leaves for photosynthesis  Leaves shade the pseudostem and ground, thereby reducing desiccation	During the drought period
Construction of ditches or contour bands	For soil and water retention	At planting  At onset of rainfall
Weeding	Reduces competition for resources e.g. soil water and nutrients	Throughout the growing season
Staking of plants	Support the weight of heavy bunches on weak or snapped plants	During the drought period
Manure application	Increased organic matter improves water retention.  Fertilizers ensure a healthy and strong plant that can withstand drought	At the onset of rains or  At planting
Tying of disintegrated pseudostem	To keep the disintegrated pseudostem intact	During the drought period
Sucker removal	Reduce competition among plants on the same mat for the scarce resources including water	Throughout the growing season, but more purposely at onset and during the drought period
Heaping soil around plant roots	Protect exposed roots from desiccation and improve water and nutrient uptake	During the drought period

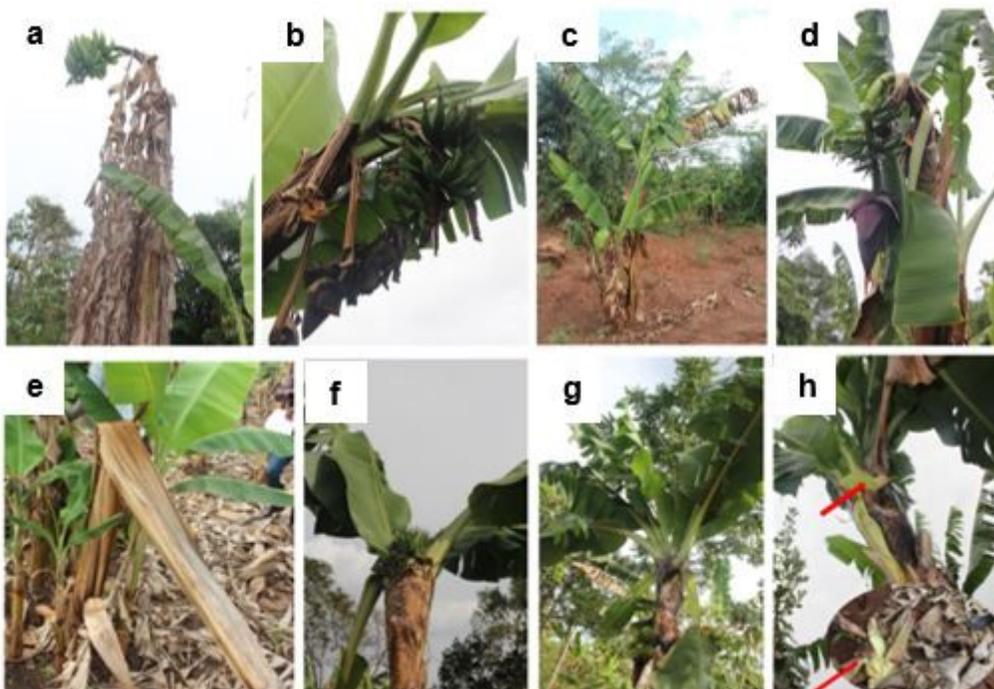
## Figures





**Figure 2**

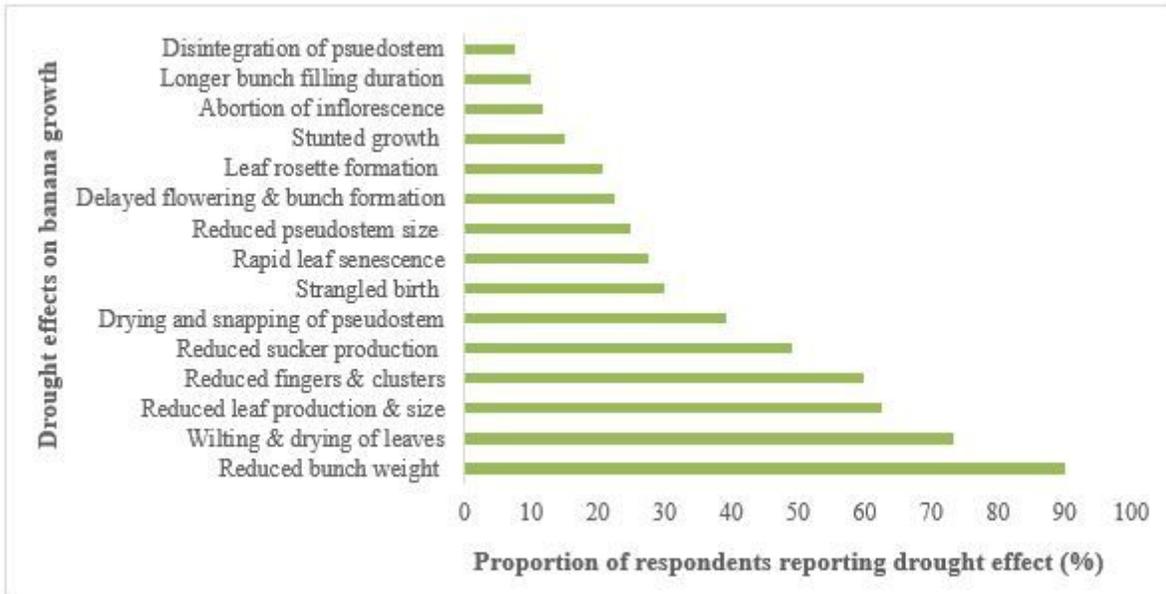
Grouping of banana cultivars grown by respondents based on the use of their end products



**Figure 3**

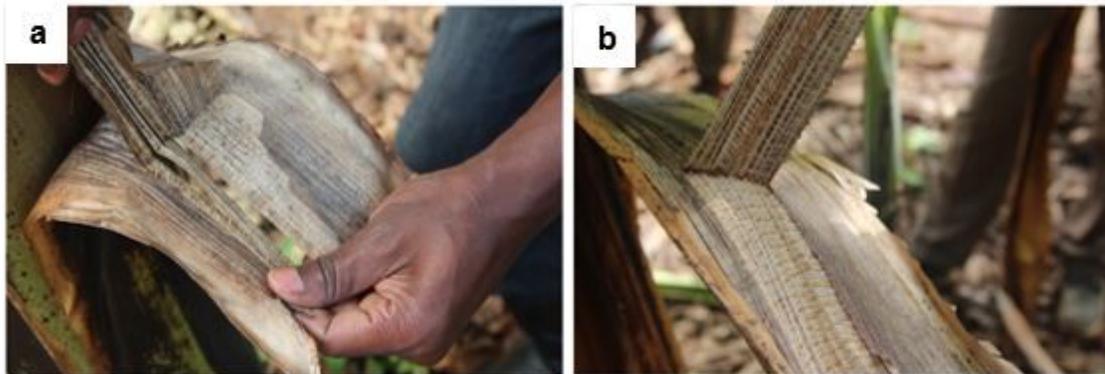
Drought stress symptoms manifested by drought-sensitive banana cultivars. (a) wilting and drying of leaves (b) reduced bunch size (c) stunted growth (d) reduced number of fingers and clusters (e) drying

and snapping of pseudostem (f) strangled birth (g) formation of petiole rosette (h) abortion of the inflorescence (upper arrow – point of attachment of inflorescence while on the plant, lower arrow - aborted inflorescence on the ground)



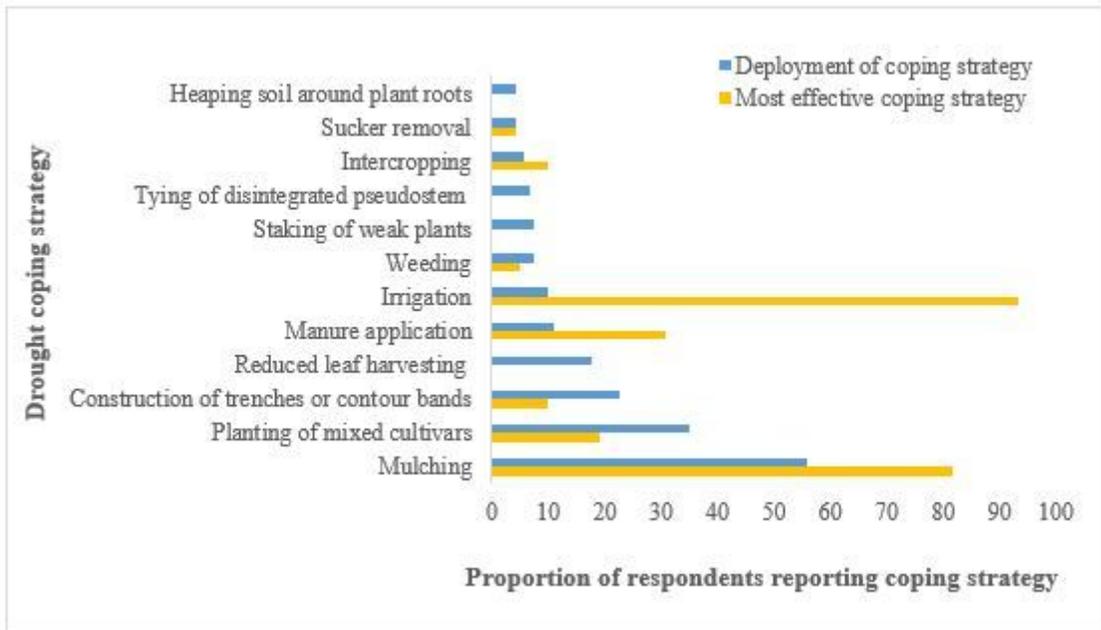
**Figure 4**

Proportion of farmers reporting different drought effects on the growth of field-grown banana cultivars in the study sites



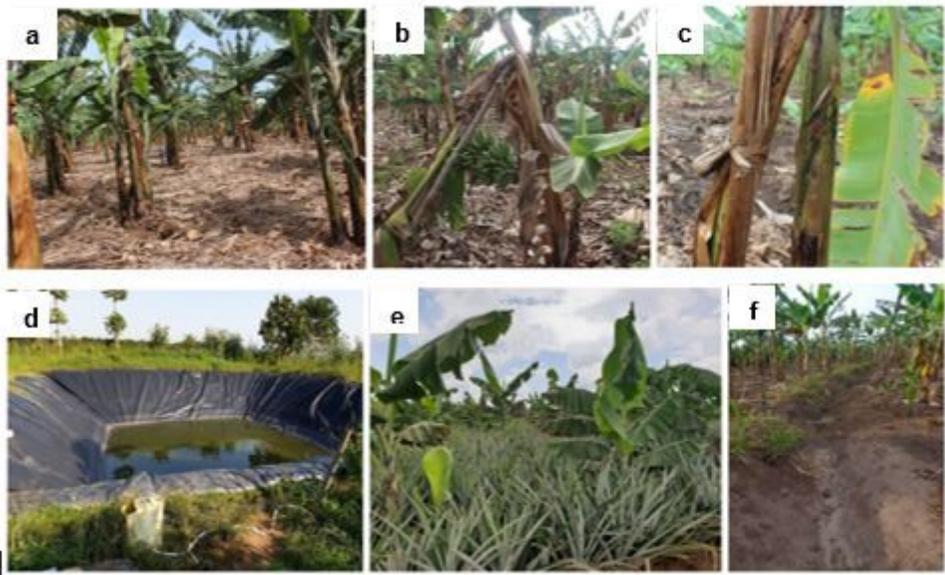
**Figure 5**

Thickness of leaf sheaths of highly drought-sensitive and moderately tolerant banana cultivars. (a) cultivar 'Mpologoma' (drought-sensitive) - thin leaf sheath layers (b) cultivar 'Nakabululu' (moderately drought tolerant)- thicker leaf sheath layers



**Figure 6**

On-farm drought stress coping strategies by banana farmers in the study districts located in the cattle corridor of Uganda



**Figure 7**

Farmers' drought stress mitigation practices in the study districts. (a) mulching with grass and banana residues (b) staking of snapped plants (c) tying of disintegrated pseudostem with banana fibres (d) water catchment from which irrigation water is drawn (e) banana intercropped with pineapple to serve as a cover crop (f) trenches for trapping soil and water