Research Article

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Assessment of the roles and farmer-preferred traits of sweetpotato in a crop-livestock farming system in Rwanda: implications for breeding dual-purpose varieties

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Abstract: In Rwanda, sweetpotato (*Ipomoea batatas* [L.] Lam) is a highly valued crop in a crop-livestock mixed farming system. The objective of this study was to assess the role of sweetpotato in the crop-livestock farming system, to identify farmer-preferred traits, and to establish farmer-led priorities in breeding dual-purpose varieties (DPVs) in Rwanda. A participatory rural appraisal (PRA) study was conducted in three selected districts of Rwanda, namely, Bugesera, Huye, and Nyagatare. Data on the uses of sweetpotato and farmers' trait preferences in sweetpotato varieties were collected and analysed. In Huye District, a high percent (56.7%) of respondents consumed sweetpotato every day, followed by Nyagatare with 53.3% consuming it at least twice a week. Most farmers (52.2%) used sweetpotato vines for livestock feed, depending on their availability. All respondents wanted to grow new sweetpotato varieties with improved root production combined with high aboveground biomass. About 87.7, 66.6, 56.6, and 51.1% of the respondents indicated that root-related traits of the crop such as high dry matter content (DMC), red skin colour, marketable root size, and yellow flesh colour were additional preferred traits, respectively. Therefore, farmers-preferred DPVs with improved root and green fodder yields could be developed to enhance the sustainable production and adoption of sweetpotato in a mixed farming system in Rwanda.

Keywords: farmer-led priorities, farmer-preferred dual-purpose varieties, *Ipomoea batatas*, participatory rural appraisal

1 Introduction

Sweetpotato [*Ipomoea batatas* (L.) Lam] is an important crop in many regions of the world. Asia and Africa are the predominant sweetpotato producing continents, contributing to 76.4 and 19.2% of the world annual production, respectively. In Rwanda, sweetpotato is the second important crop after bananas, with the total annual production of 10,82,364 tonnes (FAOSTAT 2018). Sweetpotato has multiple uses including food, animal feed, and recent breeding efforts focused on dual-purpose varieties (DPVs) (Shumbusha et al. 2019; Rukundo et al. 2020). It provides more edible energy per hectare than other food security crops such as maize, wheat, and rice (Mukhopadhyay et al. 2011). The orange-fleshed sweetpotato varieties (OFSPs) are rich in beta-carotene content, the precursor of vitamin A, an essential nutrient (Ginting 2013; Grüneberg et al. 2015). As the commercialization of storage roots increases, fresh roots with a good shape and complying with other market requirements are produced for export. In developing countries, sweetpotato is mainly cultivated for its storage roots for human consumption and its aboveground biomass for livestock feed, making it an ideal dual-purpose crop (León-Velarde 2000; Ralevic et al. 2010; Valbuena et al. 2012).

The dual-purpose nature of sweetpotato is highly valued in crop-livestock mixed farming systems in sub-Saharan Africa, including that practiced in Rwanda where the availability of agricultural lands is severely limited (Kamanzi and Mapiye 2012; Shumbusha et al. 2017; Shumbusha et al. 2019). Rwanda has a high population density estimated at 430 inhabitants km⁻² (FAOSTAT 2018). Sweetpotato is grown across varied agroecological zones in smallholder farming systems. The most suitable agroecologies for cultivating the crop are the low and mid-altitudes including the semiarid areas of Bugesera

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Figure 1: Map of Rwanda showing the study areas.

and Nyagatare, which are situated in the Eastern Province of Rwanda. The crop is produced under rainfed conditions with a bimodal rainfall pattern across the country. Consequently, most sweetpotato smallholder farmers plant and harvest around at the same time as they must match the production cycles. During planting, farmers prepare the soil manually with a hoe and planting is done either on ridges or on flat, with 30 cm within rows and 80 cm between rows. The mean on-farm yield of sweetpotato in Rwanda is 6.5 t ha^{-1} which is below the attainable mean yield of 14.2 t ha^{-1} (NISR 2017). The yield gap is attributed to biotic and abiotic stresses and socioeconomic constraints that vary across agroecologies in the country. Socioeconomic factors limiting sweetpotato production in Rwanda include: limited agricultural land; shortage of clean and adequate planting material; and poor agronomic management practices (Niyireba et al. 2013; Makokha et al. 2020).

Farming in Rwanda is characterized by fragmented small plots of land measuring less than one hectare per household (MINAGRI 2010). Each household involves in a number of interdependent farming enterprises, predominantly

in crop and livestock production. The farming systems in the country are highly heterogeneous due to variable household resources (Dixon et al. 2001). Therefore, any strategy to develop these farming systems should consider the prevailing farming practices, farmer's constraints, and the overall socioeconomic aspects (Bucagu et al. 2013). A research approach to document farmers' circumstances and constraints should involve farmers' participatory methods across the farming systems (Almekinders and Elings 2001).

Participatory research techniques have been used successfully to identify farmers' perceived production constraints, preferred crop varieties, and key traits for deployment of production packages and the development of suitable crop varieties (Ndolo et al. 2001; Ndirigwe et al. 2005; Tefera et al. 2013). Varieties like Kwezikumwe, Mugande, SPK004, and Wagabolige have shown their potential to produce high storage root and aboveground biomass yields, but varieties with strong dual-purpose ability were not yet officially released (Niyireba et al. 2013). Among participatory research techniques, the participatory rural appraisal (PRA) approach has been successfully used

in identifying farmers' constraints, preferred traits, and needs (Chiona 2010; Muhinyuza *et al.* 2012; Kivuva *et al.* 2014). Therefore, the objectives of this study were to assess the role of sweetpotato in the crop-livestock farming system, to identify farmer-preferred traits, and to clarify the objectives in breeding DPVs in Rwanda.

2 Material and methods

2.1 Study sites

The study was conducted across three selected districts of Rwanda, namely, Huye, Nyagatare, and Bugesera (Figure 1). These districts are known for their sweetpotato production. Huye District (02° 29'S, 29° 46'E) is situated in the Southern Province with an altitude of 1,700 m above sea level [masl]. Huye has an average temperature of 18.7°C with a total annual rainfall of 1,200 mm. Nyagatare and Bugesera Districts are situated in the Eastern Province and known for their mixed crop-livestock farming systems. Bugesera (02° 17' S; 30° 16' E) is located in the lowlands (<1,400 masl) with a total annual rainfall of 700–900 mm and a mean temperature of 20.8°C (Murayi *et al.* 1987). Bugesera is a hotspot area for sweetpotato virus diseases (SPVD). Nyagatare District (1° 22' 51.6" S; 30° 17' 07" E) is located in the East Savanna agroecological zone with an altitude of 1,400 masl (Nabahungu and Visser 2011). This district ranks first in livestock production in the country.

2.2 Sampling procedure and data collection

A purposive sampling (Frankel and Devers 2000) was used in order to increase the likelihood of including relevant sites and samples in the study. The following six administrative sectors were selected in the three districts: Mwogo, Ntarama, and Rweru (Bugesera District), Huye (Huye District), and Katabagema and Tabagwe (Nyagatare District). In each sector, two administrative cells were sampled, resulting in a total of 12 cells. Two villages per cell were sampled, providing a total of 24 villages for the study. In each village, three to eight farmers were sampled. This provided a total of 90 farmers sampled using semi-structured interviews. Focus group discussions (FGDs) were held involving nine focus groups comprising farmers, local leaders, and key informants. Each

focus group was composed of six to ten representative farmers who were sampled based on their experience in sweetpotato production. A total of 78 farmers participated in the FGDs across the three districts. A multidisciplinary research team was constituted for the study. The team composed of a sweetpotato breeder, two research technicians, a socioeconomist, an animal nutritionist, and local key informants.

Data were collected through semi-structured interviews, focus group discussion, and a transect walk. In addition, secondary data were collected from previous reports. Semi-structured questionnaires were used to collect data from individual farmers. Data collected through semi-structured interviews included the importance and uses of sweetpotato, constraints to sweetpotato production, farmers' interest in DPVs, and consumer preferences. FGDs were held to gather information such as importance of the crop in food security and ranking of the currently grown sweetpotato varieties and their characteristics. FGDs also included pair-wise and matrix ranking of the crops grown. Gender balance was taken into consideration by involving both male and female farmers during the semi-structured interviews and focus groups. The gender groups were essential in order to collect data on role of males and females in sweetpotato production and postharvest activities.

2.3 Data analysis

Data collected were analysed using Statistical Package for Social Sciences (SPSS) for windows Release version 21 (SPSS 2012). The analyses involved descriptive statistics and cross-tabulations in order to calculate percentage of respondents for each question or focus group. Chi-square tests were computed in order to determine associations between collected parameters and the study districts, and therefore, to make statistical inferences.

3 Results

3.1 Sources of incomes of households and forms of land ownership

Crop production activities were the main source of income for 60 and 73.3% of the respondents in the

Bugesera and Huye Districts, respectively. A mixed crop-livestock system was the main source of income in the Nyagatare District, with 76.7% farmers pursuing their livelihood in this sector (Table 1). Sources of income varied significantly across districts ($X^2 = 16.121$, $P = 0.001$). About 70, 93.3, and 100% of the respondents owned farms in Huye, Bugesera, and Nyagatare Districts, respectively. However, in the Huye District, 26.7% of respondents rented farms (Table 1). Land tenure varied significantly ($X^2 = 14.096$; $P = 0.007$) between the study districts. Approximately 45% of the interviewees had farms of less than 0.5 ha. In the Nyagatare District, 80% of the respondents had land holdings of 2 ha or more.

3.2 Uses of sweetpotato in the farming systems

About 80, 86.7, and 96.7% of the respondents used sweetpotato vines as a green fodder for livestock feed in the Huye, Bugesera, and Nyagatare Districts, respectively (Table 2). A limited number of respondents (10.2%) mentioned the use of vines as planting material, though a relatively high percentage (20%) was reported in the Huye District. Vine-based fodder was commonly used in Nyagatare District, reported by nearly all the respondents (96.7%). There were nonsignificant differences for the use of sweetpotato vines across the three surveyed districts.

3.3 Farmers' strategies to increase sweetpotato productivity

Most respondents perceived that crop improvement would be the best strategy to increase sweetpotato root productivity. This was stated by more respondents (93.3%) in the Huye District than respondents in the Bugesera and Nyagatare Districts (76.7%) (Table 3). Farmers' perceptions regarding strategies to increase root production were relatively similar across districts.

Among respondent farmers, about 86.7% in Nyagatare and 90% in both Bugesera and Huye Districts believed that improved sweetpotato varieties could bring about high levels of fodder production, whereas only 10% of respondents in Bugesera and Nyagatare Districts proposed better crop management options (Table 3). Perceived strategies to increase fodder production did not vary across districts.

3.4 Farmers-preferred sweetpotato varieties

Most respondent farmers expressed a desire for productive dual-purpose sweetpotato varieties in preference to specifically storage root or vine types. In the Huye District, most farmers (96.7%) would prefer DPVs, compared to Nyagatare and Bugesera Districts with 80 and 83.3% of farmers, respectively (Table 4). The proportions of respondents on the level of sweetpotato preferences were not significantly different across districts.

Table 1: Sources of incomes and land tenure among respondents in the three districts of Rwanda

Variable	Districts and sectors ^a							
	Bugesera			Total	Huye	Nyagatare		
	Mwogo	Ntarama	Rweru			Katabagema	Tabagwe	Total
Source of income								
Crop production	8 (26.7)	4 (13.3)	6 (20)	18 (60)	22 (73.3)	2 (6.7)	5 (16.7)	7 (23.3)
Crop and livestock production	7 (23.3)	4 (13.3)	1 (3.3)	12 (40)	8 (26.7)	5 (16.7)	18 (60)	23 (76.7)
Total	15 (50)	8 (26.7)	7 (23.3)	30 (100)	30 (100)	7 (23.3)	23 (76.7)	30 (100)
Significant test	Chi-square = 16.121; Df = 2; <i>P</i> = 0.001							
Land tenure								
Owner	15 (50)	7 (23.3)	6 (20)	28 (93.3)	21 (70)	7 (23.3)	23 (76.7)	30 (100)
Rental	0 (0.0)	1 (3.30)	1 (3.3)	2 (6.7)	8 (26.7)	0 (0.0)	0 (0.0)	0 (0.0)
Total	15 (50)	8 (26.7)	7 (23.3)	30 (100)	29 (96.7) ^b	7 (23.3)	23 (76.7)	30 (100)
Significant test	Chi-square value = 14.096; Df ^c = 2; <i>P</i> = 0.007							

^a Values in parenthesis denote percentages. ^b 1/30 of the interviewees in Huye District revealed that they borrowed land. ^c Df = degrees of freedom.

Table 2: Uses of sweetpotato vines across three districts of Rwanda

Variable	Districts and sectors							
	Bugesera			Total	Huye	Nyagatare		
	Mwogo	Ntarama	Rweru			Katabagema	Tabagwe	Total
Uses of sweetpotato vines	Respondents (%)							
Green fodder	12 (40)	7 (23.3)	7 (23.3)	26 (86.7)	24 (80)	7 (23.3)	22 (73.3)	29 (96.7)
Planting material	3 (10)	1 (3.3)	0 (0.0)	4 (13.3)	6 (20)	0 (0.0)	1 (4.3)	1 (3.3)
Total	15 (50)	8 (26.7)	7 (23.3)	30 (30)	30 (100)	7 (23.3)	23 (76.7)	30 (100)
Significant test	Chi-square = 3.936; Df = 2; P = 0.14							

Table 3: Farmers perceived strategies to increase sweetpotato production across three selected districts of Rwanda

Variable	Districts and sectors							
	Bugesera			Total	Huye	Nyagatare		
	Mwogo	Ntarama	Rweru			Katabagema	Tabagwe	Total
Farmers perceived strategies to increase storage root production					Respondents (%)			
Improved variety	12 (40)	7 (23.3)	4 (13.3)	23 (76.7)	28 (93.3)	4 (13.3)	19 (63.3)	23 (76.7)
Crop management	3 (10)	1 (3.3)	1 (3.3)	5 (16.7)	2 (6.7)	2 (6.7)	3 (10)	5 (16.7)
Education on agricultural practices	0 (0.0)	0 (0.0)	2 (6.7)	2 (6.7)	0 (0.0)	1 (3.3)	1 (3.3)	2 (6.7)
Total	15 (50)	8 (26.7)	7 (23.3)	30 (100)	30 (100)	7 (23.3)	23 (76.7)	30 (100)
Significant test	Chi-square = 4.176; Df = 4; P = 0.383							
Perceived strategies to increase green fodder production from sweetpotato vines								
Crop improvement	13 (43.3)	7 (23.3)	7 (23.3)	27 (90)	27 (90)	7 (23.3)	19 (63.3)	26 (86.7)
Crop management	2 (6.7)	1 (3.3)	0 (0.0)	3 (10)	2 (6.7)	0 (0.0)	3 (10)	3 (10)
Access to more land	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	1 (3.3)	0 (0.0)	1 (3.3)	1 (3.3)
Total	15 (50)	8 (26.7)	7 (23.3)	30 (100)	30 (100)	7 (23.3)	23 (76.7)	30 (100)
Significant test	Chi-square = 1.275; Df = 4; P = 0.866							

Table 4: Preferences of respondents (%) for sweetpotato varieties for root, fodder, or dual-purpose production in three selected districts of Rwanda

Variable	Districts and sectors							
	Bugesera			Total	Huye	Nyagatare		
	Mwogo	Ntarama	Rweru			Katabagema	Tabagwe	Total
Preferences of sweetpotato varieties				Respondents (%)				
Root production	2 (6.7)	2 (6.7)	0 (0.0)	4 (13.3)	1 (3.3)	0 (0.0)	4 (13.3)	4 (13.3)
Fodder production	1 (3.3)	0 (0.0)	0 (0.0)	1 (3.3)	0 (0.0)	1 (3.3)	1 (3.3)	2 (6.7)
Dual-purpose	12 (40)	6 (20)	7 (23.3)	25(83.3)	29 (96.7)	6 (20)	18 (60)	24 (80)
Total	15 (50)	8 (26.7)	7 (23.3)	30 (100)	30 (100)	7 (23.3)	23 (76.7)	30 (100)
Significant test	Chi-square = 4.538; Df = 4; P = 0.338							

3.5 Constraints to sweetpotato production

Respondent farmers reported several constraints to sweetpotato production. Many respondents (43.3%) reported pests as the most important constraint in the

Bugesera and Huye Districts, with 36.7% in Nyagatare (Table 5). Other constraints reported were diseases, shortage of planting material, and drought. Nonsignificant differences were detected between districts and sectors for the reported constraints.

Table 5: Major constraints to sweetpotato production in three selected districts of Rwanda

Variable	Districts and sectors							
	Bugesera			Total	Huye	Nyagatare		
	Mwogo	Ntarama	Rweru			Katabagema	Tabagwe	Total
Major constraints to sweetpotato production based on farmer-researcher discussion								
Pests	5 (16.7)	3 (10)	5 (16.7)	13 (43.3)	13 (43.3)	3 (10)	8 (26.7)	11 (36.7)
Diseases	7 (23.3)	2 (6.7)	2 (6.7)	11 (36.7)	9 (30)	3 (10)	3 (10)	6 (20)
Soil degradation	1 (3.3)	1 (3.3)	0 (0.0)	2 (6.7)	1 (3.3)	0 (0.0)	0 (0.0)	0 (0.0)
Shortage of clean planting material	0 (0.0)	1 (3.3)	0 (0.0)	1 (3.30)	4 (13.3)	0 (0.0)	7 (23.3)	7 (23.3)
Lack of market	2 (6.7)	1 (3.3)	0 (0.0)	3 (10)	1 (3.3)	0 (0.0)	0 (0.0)	0 (0.0)
Lack of processing facility	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	3 (10)	3 (10)
Drought	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	2 (6.7)	1 (3.3)	2 (6.7)	3 (10)
Total	15 (50)	8 (26.7)	7 (23.3)	30 (100)	30 (100)	7 (23.3)	23 (76.7)	30 (100)
Significant test	Chi-square = 20.478; Df = 12; <i>P</i> = 0.059							
Major constraints based on focus group discussion								
Constraint	Districts			Total scores	Overall ranking			
	Bugesera Rank and scores	Huye Rank and scores	Nyagatare Rank and scores					
Lack of planting material	1 (6)	—	1 (7)	13	2			
Virus disease	2 (5)	3 (4)	3 (5)	14	1			
Drought	3 (4)	2 (5)	5 (2)	11	3			
Insects	4 (3)	4 (3)	6 (1)	7	5			
Lack of market	5 (2)	—	—	2	8			
Weevils	—	5 (2)	2 (6)	8	4			
Lack of postharvest facilities	—	—	4 (4)	4	7			
Lack of dual-purpose varieties	—	1 (6)	—	6	6			
Poor soil fertility	—	6 (1)	—	1	9			

—: Not ranked among the preference crops grown in the district and data did not allow to conduct significant tests.

The top two main constraints to sweetpotato production identified through focused group discussion were SPVD and a lack of planting material. SPVD was described as a major constraint (Table 5) in all three surveyed districts. A lack of DPVs and poor soil fertility were the overriding constraints specific to Huye District, whereas weevils and a lack of postharvest facilities were reported as the main constraints in Nyagatare District.

3.6 Major characteristics of farmers-preferred sweetpotato varieties for storage root production

About 50 and 76.6% of farmers preferred marketable storage roots, in the Bugesera and Huye Districts,

respectively, whereas in the Nyagatare District the farmers wanted medium-sized roots (Table 6). Nonsignificant differences existed between districts and sectors in their choice of storage root size. Across districts, 50, 60, and 90% of respondents expressed their need for sweetpotato varieties with roots of red skin colour, respectively, in the Nyagatare, Bugesera, and Huye Districts. White-fleshed storage roots were preferred by 50% of respondents in Bugesera and 63.3% in Nyagatare. Most farmers (73.3%) in Huye District preferred yellow-fleshed types. Districts and sectors differed significantly for flesh colour ($X^2 = 23.396$; $P = 0.001$) and skin colour ($X^2 = 12.15$; $P = 0.016$) preferences. High dry matter content (DMC) was preferred by most respondents across all sites. Over 80% of respondents preferred high DMC in Bugesera and Huye, and 96.7% respondents in Nyagatare preferred this trait. Farmer preferences in terms of DMC were similar across districts.

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expected, a fodder system based on sweetpotato vines was commonly used in Nyagatare, a district with the most live-stock production in Rwanda. Most farmers reported using sweetpotato vines as a fodder across all districts. This could explain the shortage of vines at different times of the year in the country. This reflects the need for sweetpotato varieties with strong dual-purpose attributes and for different vine cutting regimes. Only a few numbers of farmers used roots for household food processing, indicating that the crop has not been fully exploited in local food processing.

4.3 Strategies to increase sweetpotato productivity

Farmers' perceptions regarding strategies to increase root production were similar across districts (Table 3). Respondents perceived that cultivar improvement would be the best way to increase sweetpotato root productivity, concurring with the previous results of Rukundo et al. (2015). This reflects the need to develop and disseminate new varieties with improved root yields. Similarly, most farmers expressed interest towards new varieties with greater fodder production potential (Table 3).

4.4 Preferences of dual-purpose sweetpotato varieties

Most respondents in all districts expressed their need for DPVs, especially in Huye District (Table 4). Almost all the respondents (96.7%) in Huye chose to grow DPVs instead of other types, which could be explained by the high population density characterizing the area and limited agricultural lands. In their previous findings, Kamanzi and Mapiye (2012) and FAOSTAT (2018) pointed out similar observation regarding the need of crops with multiple uses. The high level of farmer preference for dual-purpose types was similar and consistent across the study districts, indicating that any effort to develop these varieties should meet the needs of all the districts.

4.5 Constraints to sweetpotato production

There were several constraints to sweetpotato production such as: pests, diseases, shortage of clean planting material,

lack of DPVs, and drought (Table 5). Pests were reported by respondents as the most important constraint across districts; diseases were specifically reported in Bugesera District. These results were in agreement with Rukundo et al. (2015) who reported that pests and diseases were among the top five constraints to sweetpotato production in Rwanda. The high frequency of diseases in Bugesera District, especially SPVD, may be attributed to the suitability of this agroecology, which is a semiarid area with high temperatures favourable for disease development (Nduwumuremyi et al. 2016). Njeru et al. (2008) reported a high prevalence of SPVD in the area. Dual-purpose types are not yet widely grown in Huye District because farmers were not aware of these varieties.

4.6 Major characteristics of the preferred storage root

In Bugesera and Huye Districts, 50 and 76.6% of farmers preferred marketable root size of storage roots, respectively (Table 6). This reflects the commercial value of the crop, which is steadily increasing across districts. Relatively few farmers preferred marketable roots in Nyagatare District because of the commercial value of other crops such as maize and rice. Most farmers preferred red skin colour. Similarly, Ndirigwe et al. (2005) reported that red skin colour was consistently liked over time in Rwanda. In the Bugesera and Nyagatare Districts, white-fleshed sweetpotato varieties were preferred over cream, yellow, and orange flesh colour (Table 6). The study of Hagenimana et al. (1998) indicated that orange flesh storage root colour strongly correlated with low DMC in sweetpotato, and therefore, OFSPs were not popular with farmers. Several researchers (Mwanga and Ssemakula 2011; Kirimi et al. 2013; Low et al. 2013) have reported the potential value of OFSPs because of their high total carotenoids content, a precursor of vitamin A. Most of the respondents across all study districts expressed a clear preference for sweetpotato varieties with high DMC, agreeing with the results of previous studies (Chiona 2010; Laurie 2010; Sseruwu 2012). Breeding of sweetpotato in the study areas should take into consideration these farmers' preferred traits.

5 Conclusions

The study revealed the importance of sweetpotato as a food security crop with dual-purpose potential in

Rwanda. All respondents expressed interest in growing sweetpotato varieties with improved root production combined with high aboveground biomass. About 87.7, 66.6, 56.6, and 51.1% of the respondents indicated that root-related traits of the crop such as high DMC, red skin colour, marketable root size, and yellow flesh colour were additional preferred traits, respectively. Therefore, farmers-preferred dual-purpose sweetpotato varieties with improved root and green fodder yields should be developed to enhance sustainable production and the adoption of sweetpotato in the mixed farming systems in Rwanda.

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