Musa germplasm diversity status across a wide range of agro-ecological zones in Rwanda

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ABSTRACT

Objectives: This study assessed the on-farm *Musa* germplasm diversity across different agro-ecologies of Rwanda and the socio-economic utilization options and selection practices that create/maintain this diversity on-farm.

Methodology and results: A *Musa* germplasm diagnostic survey was carried out in 2007 in five Rwandan districts on a transect from Lake Kivu (West) to Kirehe district (East) bordering Tanzania. Across all sites, 118 farms, each having at least 50 mats were sampled for determining *Musa* diversity. Forty three *Musa* cultivars were recorded across the five districts. Higher diversity was observed in the east declining westwards to the Lake Kivu region as reflected by the number of cultivars and their relative abundance. Nearly half of the recorded cultivars had a low diversity index (Gini-Simpson 1-D < 0.2) and therefore prone to genetic erosion. Cooking cultivars only dominate in the district of Kirehe, while beer cultivars dominate the banana production landscape in the other districts. Taste/flavor, bunch size and market demand were the most important criteria for banana cultivar selection and thus greatly influenced cultivar conservation and distribution on-farm. Diseases such as Fusarium wilt and Xanthomonas wilt greatly contributed to genetic erosion.

Conclusion and application of results: Musa cultivar diversity in Rwanda is under threat. *Ex-situ* conservation of the menaced cultivars is of crucial importance. Beer cultivars dominated the landscape. Cultivar diversity on-farm was influenced by the prevailing altitude; taste/flavor, bunch size, and market demand of the cultivars; and their susceptibility to diseases especially Fusarium and Xanthomonas wilt. Banana breeding or adaptation strategies therefore should take into account the farmer preferred traits. In addition, strategies for managing these diseases are critical for preventing the genetic erosion of the affected cultivars.

Keywords: cultivar evenness, cultivar richness, diversity index, genetic erosion

INTRODUCTION

The Great Lakes region of East Africa, of which Rwanda is part, constitutes one of the secondary centers of *Musa* diversity, especially for the East African highland bananas, AAA-EA (Karamura *et al*., 2004). Banana and plantain (*Musa* sp.) is an important staple and income-generating crop

grown by up to 90% of households in Rwanda (Lassoudière, 1989). Rwanda with the total estimated banana production of 2.65 MT/year ranks among the top 20 banana producers in the world (FAOSTAT, 2008). Banana consumption in Rwanda is one of the highest in the Great Lakes region and is estimated at an annual per capita consumption of 258 kg (Jagwe *et al.*, 2008). In Rwanda, banana covers 23% of the total cultivated land (Mpyisi *et al.*, 2000), is produced all year round and thus improving food security and significantly contributing to the resilience of the agro-ecological landscape. Its soil conserving properties through its canopy, root system and mulching a common practice in banana plantations are important for soil conservation in Rwanda that has an undulating terrain. For example, Lufafa *et al.* (2003) reported 30% lower erosion levels in fields cropped with bananas compared to those with annual crops. However, banana fruits are now also massively imported in Rwanda, mainly from Uganda, Tanzania and the Democratic Republic of Congo. This has partly been attributed to falling productivity as a result of banana diseases and demographic pressure which has led to land fragmentation and deterioration of the natural resource base (Jagwe *et al.*, 2008). This region has indeed suffered a great decline in *Musa* production and germplasm diversity in the last ten to twenty years. The decline in *Musa* germplasm diversity in Rwanda has been due to land pressure, pests, diseases and plant nutritional problems (Okech *et al.*, 2002 and 2005). In addition, population migrations before and during the 1994 genocide led to the disappearance or renaming of some cultivars (Nsabimana and van Staden, 2005) thus creating confusion in the nomenclature of cultivars. The 1994 genocide also disrupted the operations of the Rwanda banana programme leading to loss of archived information and a complete staff turnover (Okech *et al.*, 2002 and 2005).

MATERIALS AND METHODS
This study was conducted in 2007 through an on-farm *Musa* diagnostic survey in five banana growing, Rwandan districts located along a transect ranging from

Such deterioration necessitated an urgent assessment of the current extent of diversity available in the country and its characterization in order to take some conservation and developmental actions. In effect, there have already been various efforts to collect and conserve *ex-situ* the genetic diversity of *Musa* in Rwanda. For example, 90 accessions from the existing *ex-situ* collection at ISAR, Rubona were characterized (Nsabimana and van Staden, 2005). Various socioeconomic, marketing and agro-ecological constraints are known to play an important role in farmers' choices and management of crop genetic diversity at the farm, agro-ecosystems and community levels (Gauchan *et al.*, 2005). *Ex-situ* facilities cannot always accommodate the full range of useful diversity; conserve the dynamic process of crop evolution and farmers knowledge of crop selection and management inherent in the development and evolution of local cultivars (Bellon *et al.*, 1997; Fowler and Hodgkin, 2005). As such, on-farm conservation of genetic resources is increasingly being given a high attention (Bretting and Duvick, 1997; Bellon *et al.*, 1997; Brush, 2004; Fowler and Hodgkin, 2005). However, the genetic erosion of *Musa* diversity is most likely going to continue in Rwanda with the ongoing government policy of market-driven production and regionalization of crop cultivation, including bananas, into few but 'high potential' agro-ecological zones. Thus, an on-farm study of the *Musa* germplasm diversity, the key selection practices and agro-ecological factors influencing this diversity was still needed to further support *Musa* conservation and development in Rwanda. The objectives of this study were therefore to assess the on-farm *Musa* germplasm diversity across different agro-ecologies of Rwanda and the socio-economic utilization options and selection practices that create/maintain cultivar diversity on-farm in these agro-ecological niches.

Rusizi, bordering Lake Kivu (Western Province), to Kirehe district (Eastern Province) at the border with Tanzania. The other sampled districts included

Bugesera in the Eastern province, Ruhango in the Southern province and Karongi in the Western province (Fig 2). Rainfall and temperature in Rwanda vary with the variation in altitude. Rwanda generally receives much rainfall, though rains can be erratic in the East (Verdoodt and Van Ranst, 2003). Rwanda receives the highest rainfall in the Western Highlands and lowest rainfall in the Eastern lowlands (Verdoodt and Van Ranst 2003). The high altitude regions (Western) have the lowest mean temperatures (16-17°C), while higher temperatures are observed in the central plateau (18-21°C) and in the Eastern Plateau and the Western lowlands (20-24°C) (Verdoodt and Van Ranst, 2003). Rwanda has four different seasons: a short dry season (January to February); a long rainy season (March to May); a long dry season (June to mid-September) and a short rainy season from mid-September to the end of December (Verdoodt and Van Ranst, 2003). Little variations in temperatures are noted throughout the year, though diurnal fluctuations can exceed 12°C.

The five districts were sampled based on the importance of the *Musa* crop in the farming system and the variability in the agro-ecologies. This was anticipated to offer a higher chance of capturing a more representative *Musa* cultivar diversity in the country. Bananas in Rwanda are often grown in association with one or two other important crops, including beans, sweet potatoes, cassava, sorghum and yam (Sebasigari, 1985; AATF, 2009). The five districts cut across a range of agro-ecologies (agricultural zones). Delepierre (1974) delimited 12 agricultural zones in Rwanda, based on differences in altitude, rainfall regime and soil properties (Table 1). Each of these zones has a unique combination of land resources that determines the range of well-adapted crops (Verdoodt and Van Ranst, 2003).

Table 1: Characteristics of the agricultural zones in Rwanda

Zone		Altitude(m)			Rainfall(mm)			Soil	Agricultural value
n°	name	min	avg	max	min	avg	max		
1	Imbo	970	1,100	1,400	1,050	1,200	1,600	alluvial	excellent
2	Impara	1,400	1,700	1,900	1,300	1,400	2,000	very fine, red, < basalt	good
3	Lake Kivu Border	1,460	1,600	1,900	1,150	1,200	1,300	shallow, clay loam	excellent-good
4	Birunga	1,600	2,200	2,500	1,300	1,500	1,600	volcanic	excellent
5	Congo-Nile Watershed Divide	1,900	2,100	2,500	1,300	1,600	2,000	humiferous, acid	moderate
6	Buberuka Highlands	1,900	2,000	2,300	1,100	1,200	1,300	laterite soil	good
7	Central Plateau	1,500	1,700	1,900	1,100	1,200	1,300	humiferous	good
8	Granitic Ridge	1,400	1,600	1,700	1,050	1,100	1,200	coarse, gravely	moderate
9	Mayaga	1,350	1,450	1,500	1,000	1,050	1,200	clayey, < schists	very good
10	Bugesera	1,300	1,400	1,500	850	900	1,000	strongly weathered	poor
11	Eastern Plateau	1,400	1,500	1,800	900	950	1,000	laterite soil	moderate–good
12	Eastern Savanna	1,250	1,400	1,600	800	850	900	strongly weathered	very poor

Source: Verdoodt and Van Ranst, 2003

Rusizi district falls in the Imbo and Imapra zone; Karongi in the Lake Kivu Borders; Ruhango across Central Plateau, Granitic Ridge and Mayaga zones; Bugesera across the Mayaga and Bugesera zones; and Kirehe district across the Eastern Plateau and the Eastern Savanna zones. MINAGRI, (2003) reported the Imbo, Impara, Kivu Lake Borders, Eastern Plateau and Eastern Savanna as the main banana cultivation zones. In contrast, the land suitability classification ranks the suitability of the East ranges between moderate and marginal because of the low rainfall, while the Mayaga and the peripheral part of the Bugesera as moderately

suitable (Verdoodt and Van Ranst, 2003). Agricultural zones 4, 5, 6 and 12 are of no importance to banana production following the crop regionalization (Verdoodt and Van Ranst, 2003). The socioeconomic characteristics such as the gender and wealth status typology (i.e. poor, moderately rich and rich); easy access to markets; and presence of local farmers' institutions and NGOs interested in banana production and with the capacity to scale out research results were also considered in sampling of districts. This study built on participatory rural appraisals (PRA) and baseline surveys, which were conducted by CIALCA in the framework of the CIALCA consortium in the same districts in 2006 (CIALCA, 2008). The PRA and baseline surveys were executed in sites cutting across existing biophysical/ socioeconomic gradients of banana production potential in Rwanda. Whereas the PRA and baseline surveys were solely based on information derived through focus group discussions and household interviews, this farm diagnostic survey took a step further to quantify farming systems through actual field measurements. Interview schedules with open and close ended questions were used to capture data in this study. Across all sites, 118 farmers were sampled along the transect using a random systematic method. Sampling was done on farms that had at least 50 banana mats. The mean altitudes of the sampled farms varied across the five surveyed districts. The altitudes of farms sampled in Rusizi district in the Western province bordering the southern tip of Lake Kivu ranged from 1,594 to 1,706 masl. Karongi district also bordering Lake Kivu had altitudes ranging from 1,440 to 1,559 masl, meanwhile in Ruhango district in the Southern province altitudes ranged from 1,339 to 1,543 masl. The Eastern province districts of Bugesera and Kirehe were located at altitude ranges from 1,310 to 1,595 masl. The diagnostic survey focused on on-farm *Musa* germplasm diversity, socio-economic utilization options/practices that create/maintain cultivar diversity on-farm and cultivar disappearance/genetic erosion. *Musa* cultivar names obtained during farmer interviews were subsequently reviewed by the Rwanda banana program staff and checked against the National Banana Germplasm Collection database of the Rwandan Agricultural Research Institute (ISAR), Rubona research station. SPSS statistics 17.0 (IMB corporation, 2008) and MS Excel were used to analyze descriptive data and generate frequency distribution tables and charts. *Musa* germplasm diversity was quantified using the number (richness) *(Equation 1)* and relative abundance of cultivars *(Equation 2)* in the study

sites or ecosystem, often referred to as species diversity. Species diversity is a function of the number of species present (richness) and the evenness or equitability (relative abundance) of each (Hurlbert, 1971). These diversity indices determine which populations to target for conservation to maximize diversity or to model services provided by diversity (Gauchan *et al*., 2005). Species richness sums the number of different distinct *Musa* cultivars regardless of their frequencies across study communities. Species richness is the diversity of order zero and is completely insensitive to cultivar frequencies (Jost, 2006). It gives equal weight to those cultivars represented by very few plants as to those represented by many plants (Jost, 2006; Dyke, 2008; Colwell, 2009).

$$D = \sum_{i=1}^{s} P_i^0 \quad \textit{Equation 1}$$

where cultivar i comprises the proportion Pi of the total individuals in a community of S individuals, 0 denotes diversity of order zero.

Simpson index expressed as Gini-Simpson/ Simpson index of diversity 1–D was used as the measure of relative abundance (*Equation 2*). The Gini-Simpson index (1-D) i.e. evenness is a measure of how similar species are in their abundances (Magurrun, 1988). The opposite of evenness is dominance, which is the extent to which one or a few species dominate the community (Magurrun, 1988). This index takes account of the number of individuals of each cultivar as well as the number of cultivars within a community (Gauchan *et al*., 2005; Jost, 2006). It is conventional to equate high diversity with high evenness (equivalent to low dominance) (Magurrun, 1988).

Gini-Simpson $1-D = \sum_i \{n_i \times (n_i - 1)\} / (N \times (N - 1))$ *Equation 2*

where n_i is the number of individuals of cultivar *i* and *N* is total number of individuals of all cultivars.

GenStat 11th Edition (VSN International Ltd, 2008) was used to compute species richness and the Simpson 1-D indices.

To determine the most important *Musa* cultivar selection criteria influencing the diversity of cultivars on-farm, farmers selected and ranked nine different cultivar selection criteria in order of importance. Farmers' responses were then compiled and the means subjected to a multivariate principal components analysis using GenStat 11th Edition (VSN International

Ltd, 2008) to determine the most important selection criteria across farms.

RESULTS

Cultivar diversity: Forty three different *Musa* cultivars were recorded across the five districts of Rwanda (Table 1). A higher *Musa* cultivar diversity was observed in the Eastern province declining to the west as shown by the number of cultivars (Table 1) and the Gini-Simpson index of diversity (which is a measure of relative abundance) (Fig. 1). Karongi district (in the West) with 12 cultivars had the least number of cultivars recorded on-farm, while Bugesera (24 cultivars) and Kirehe (23 cultivars) in the East, boasted of the highest number of cultivars on-farm among the studied districts in Rwanda (Table 1). Similarly, the western district of Karongi had the least Gini-Simpson indices of 0.697 (i.e. dominated by fewer cultivars) compared to 0.79 and 0.85 in Bugesera and Kirehe in the west, respectively (Fig. 1). For example, the four most predominant cultivars occupied 84% and 88% of the *Musa* production landscapes in the western districts of Karongi and Rusizi, respectively compared to 70% and 72% in Kirehe and Bugesera, respectively (Table 1).
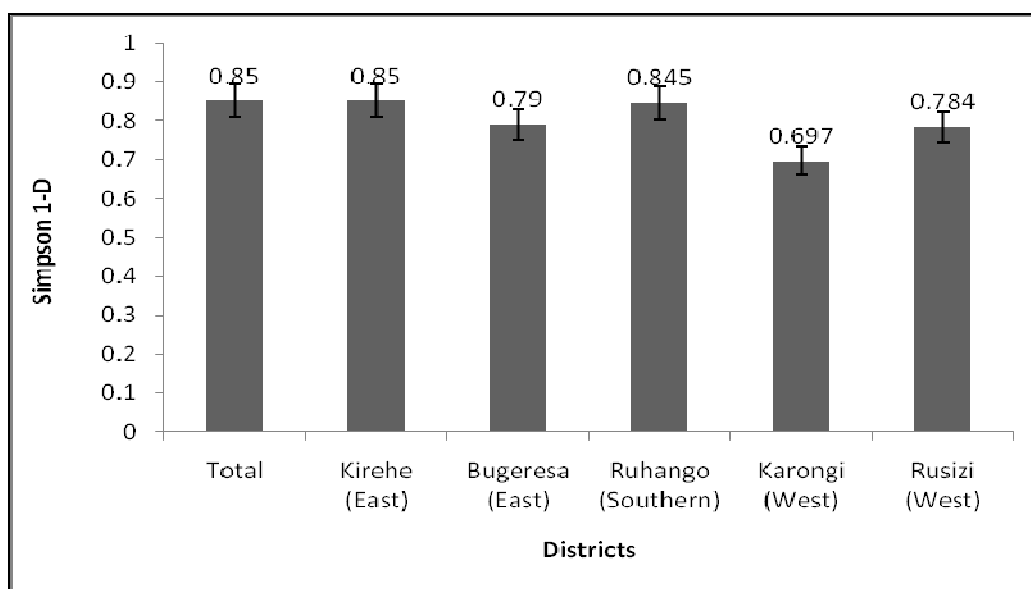

Figure 1: Gini-Simpson indices of diversity of *Musa* cultivars assessed during a germplasm survey in 2007 in Rwanda. The study covered five districts of Kirehe (in the East), Bugeresa (East), Ruhango (Southern), Karongi (West) and Rusizi (West). Vertical bars are jackknife standard errors. Only four of the 43 cultivars, i.e. 'Intuntu' (AAA-EA, beer), 'Gros Michel' (AAA, dessert), 'Ingenge' (AAA-EA, cooking) and 'Kamaramasenge' (AAB, dessert) were widely grown across the five districts.

Five other cultivars 'Indaya' (AAA, beer), 'Mujuba' (AAA-EA), 'Mbwaziruma' (AAA–EA), 'Intokatoke' (AAA-EA) and 'Poyo' (AAA, dessert) were grown across four districts (Table 1). Most of the 43 *Musa* cultivars i.e. 48% were only found grown in one district. The AAA-EA beer cultivars still dominate the *Musa* landscape in Rwanda (67% of landscape) with the cultivars 'Intuntu' (AAA-EA group, 33% of area), 'Indaya' (AAA-EA, 11%), 'Umuzibwe' (AAA-EA, 7.3%), 'Kayinja' (ABB, 6.9%) and 'Intokatoke' (AAA-EA, 5.6%) as the prominent ones (Table 1). Important cooking cultivars in Rwanda are the AAA-EA cooking bananas 'Barabeshya' (5.2%), 'Ingaju' (3.7%), 'Mujuba' (2.9%), while 'Poyo' (AAA, 4.5%) and 'Kamaramasenge' (AAB, 1.7%) are the important dessert cultivars. Beer cultivars predominate in the Western province (71-78% of area under *Musa*) declining eastwards as cooking banana gain in importance (Fig. 2). The AAA-EA highland beer cultivar 'Intuntu' dominates among the beer types (21to 52%). Cooking cultivars dominate in Kirehe in the east (Fig. 2) occupying up to 60% of the banana landscape in the district. The area under dessert cultivars varied between 4% in the Western districts and 15% in Ruhango district. Area under dessert types in Bugesera

and Kirehe districts was 13 and 10%, respectively. 'Muzuzu' (AAB) mainly eaten cooked or used for beer making was the only plantain cultivar recorded in this

study. Only 4% and 0.2% of this cultivar was recorded in Bugesera and Kirehe districts, respectively.
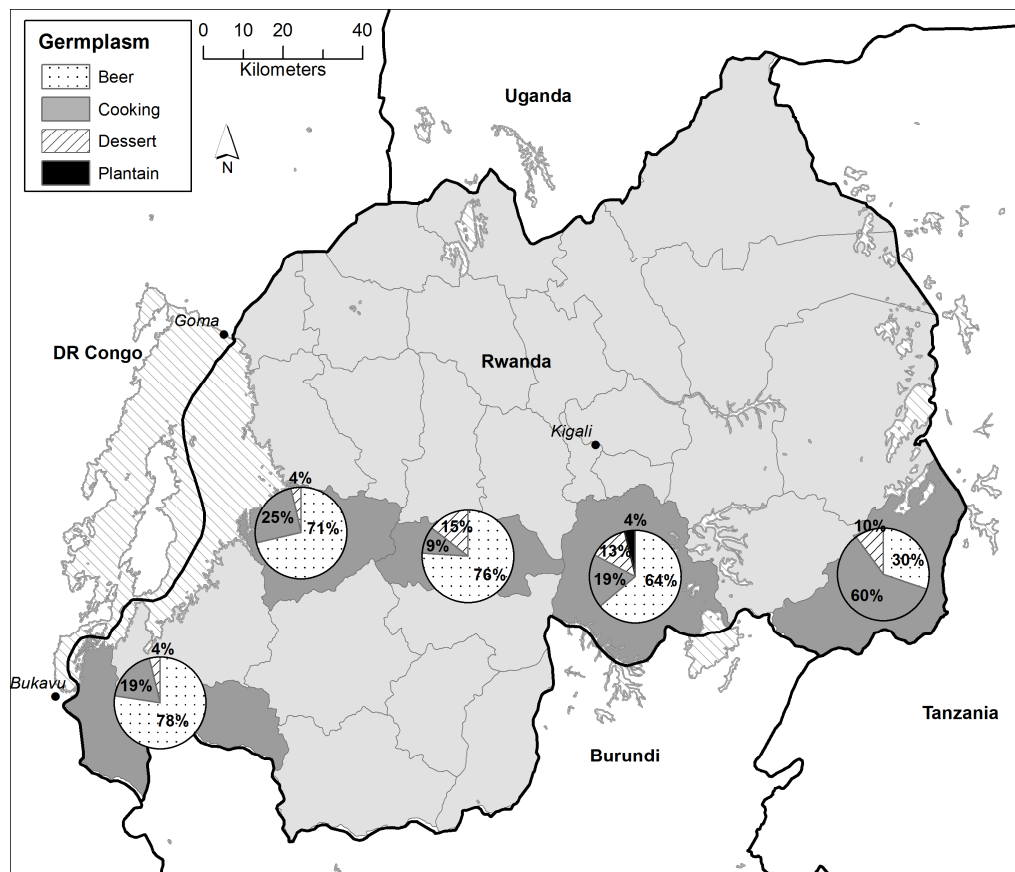

Figure 2: Map of Rwanda showing *Musa* cultivar distribution (% mat count) by use groups (i.e. beer, cooking, dessert and plantain) in five surveyed districts in 2007. From east (Tanzania border) to West (DR Congo border) are Kirehe, Bugesera, Ruhango, Karongi and Rusizi districts, respectively.

Several cultivars including 'Intuntu' (beer), 'Intokatoke' (beer), 'Ingaju' (cooking), 'Ikinyangurube' (AAA, dessert), 'Kampala' (AAA-dessert), 'Mavuta' (AAA-EA, beer), 'Icyerwa' (AAA-EA, cooking), 'Gisukari' (AAA, dessert) and Muzuzu (AAB, plantain) had multiple uses to the farmers. Most farmers observed that the dessert types helped improve the potency and quality of beer. *Musa* diversity on the basis of genome groups revealed dominance of the East African highland banana, *Musa* AAA-EA (81%) (Table 3). Other AAA types and the

ABB types were tied up at 7%. Cavendish AAA types, the AAB dessert types and AAB plantain types accounted for only 1.0%, 2% and 0.8% of the landscape, respectively. Ruhango district in the Southern had the least concentration of East African highland bananas (AAA-EA) (66%). It had a relatively high (19%) concentration of the ABB types. In contrast the West had the highest frequency of AAA-EA types (93 to 97% of the landscape) (Table 3).

Table 2: *Musa* cultivars listed in five districts of Rwanda, their respective genome groups, use and mat coverage (%) in a *Musa* germplasm diagnostic survey in 2007. A dash (-) indicates the cultivar was not detected in this location in this survey.

Cultivar name	Genome group	Traditional Use	*Musa* mat coverage (%)					
			Percent total	Rusizi (West)	Karongi (West)	Ruhango (Southern)	Bugeresa (East)	Kirehe (East)
Intuntu[1]	AAA	Beer [C]	33.0	35.64	51.63	21.17	42.55	23.28
Indaya[2]	AAA	Beer	11.0	2.27	10.82	24.77	17.41	-
Umuzibwe	AAA	Beer	7.3	21.77	8.89	-	-	-
Kayinja[3]	ABB	Beer	6.9	-	-	19.05	-	3.08
Intokatoke	AAA	Beer/Cooking	5.6	13.03	-	3.54	1.71	2.89
Barabeshya	AAA	Cooking	5.2	17.36	-	-	-	-
Poyo	AAA	Dessert	4.5	-	1.53	10.30	6.08	1.54
Ingaju	AAA	Cooking [B]	3.7	-	-	-	1.30	27.99
Mujuba	AAA	Cooking	2.9	-	11.61	3.08	4.42	1.06
Nyiramabuye[N]	AAA	Beer	1.9	-	-	6.93	-	-
Kamaramasenge	AAB	Dessert	1.7	1.42	0.73	0.33	1.30	7.02
Injagi[4]	AAA	Cooking	1.4	-	-	-	0.27	10.49
Gros Michel[5]	AAA	Dessert	1.2	2.14	1.00	0.25	5.67	1.49
Mbwaziruma	AAA	Cooking	1.2	-	0.93	1.06	2.71	2.07
Ikinyangurube[6]	AAA	Multiple	1.1	0.06	-	3.58	0.24	-
Inzirabahima	AAA	Cooking	1.1	0.70	-	3.12	-	0.34
Kampala[7]	AAA	Beer [D]	1.1	3.63	-	-	-	-
Icyerwa*	AAA	Cooking [B]	1.0	-	-	-	-	7.89
Intutsi	AAA	Cooking	0.9	-	-	-	4.01	-
Nyakitengwa[8]	AAA	Cooking [B]	0.9	-	9.49	-	0.54	0.05
Ingenge[9]	AAA	Cooking	0.8	0.43	2.99	0.19	1.62	3.32
Muzuzu[10]	AAB	Roasting[C,B]	0.8	-	-	-	3.90	0.20
Rumaripfa[N]	AAA	Cooking	0.8	-	-	-	3.58	-
Inyamunyo	AAA	Cooking	0.5	-	-	1.83	-	-
Ingumba	AAA	Cooking/Beer	0.4	-	-	-	1.25	0.87
Ishika	AAA	Beer	0.3	1.17	-	-	-	-
Bakungu[11]	AAA	Cooking	0.2	-	-	-	-	1.59
Ingagara	AAA	Cooking	0.2	-	-	-	-	1.59
Intembe	AAA	Beer	0.2	-	-	0.42	0.35	-
Inyoya	AAA	Cooking	0.2	-	-	-	-	2.31
Gisukari[12]	AAA	Dessert [B]	0.1	0.17	-	0.10	0.14	-
Igihuna	AAA	Beer	0.1	0.02	-	0.08	0.24	-
Incakara	AAA	Cooking	0.1	-	-	-	0.27	0.05
Inyarwanda	AAA	Cooking	0.1	-	-	0.21	-	-
Mutsimawuburo[13]	AAA	Cooking	0.1	-	-	-	0.24	0.34
Umugumira[N]	AAA	Beer	0.1	-	-	-	0.38	-
Bushoki[N]	AAA	Cooking	0.0	-	0.20	-	-	-
Gisubi	AB	Beer	0.0	-	0.20	-	-	-
Indundi[N]	AAA	Cooking	0.0	0.08	-	-	-	-
Intobe	AAA	Cooking	0.0	-	-	-	-	0.29
Inyabupfunsi	AAA	Cooking	0.0	0.12	-	-	-	-
Isha	AAA	Beer	0.0	-	-	-	0.11	-
Kintu	AAA	Cooking	0.0	-	-	-	-	0.34

Synonyms: 1: 'Inkara' and 'Insiri'; 2: 'Yangambi Km[5]' and 'Kanuka'; 3: Pisang Awak; 4: 'Incakara'; 5: 'Mbogoya' and 'Mavuta'; 6: 'Petite Naine' and 'Grande Naine'; 7: 'Madame' and 'Prata'; 8 'Mitoki';9: 'Inyabutembe'; 10:

'Umushaba1'= false Horn plantain and 'Umushaba2' = French Plantain 11: 'Makungu'; 12: 'Gisukari red' (red fruit skin variety) and 'Gisukari green' (yellow fruit skin variety); and 13: 'Inzirabushera';
N: Not present in the ISAR Rubona *Musa* germpasm collection,
Foc: Lost from the ISAR collection due to Fusarium wilt disease
*****: Two types of 'Icyerwa'- with small or big fingers
#: Has both cooking and brewing types
Other cultivar uses: C= cooking; B= beer; D = Dessert; R= Roasting

Selection criteria on-farm: The first (PC1) and second (PC2) principal components for the nine *Musa* selection criteria ranked by farmers accounted for 100% of the variation (Table 4). The first PC assigned nearly equal loading across the variables in all the *Musa* use groups (i.e. beer, cooking, dessert and roasting). The second PC gave a higher loading to taste/flavor/quantity of juice produced, market demand and bunch size for the beer, cooking and dessert group (Table 4). The results suggest that these criteria are the most important for banana selection in Rwanda. On the contrary, ability of *Musa* plants to mature early and the ability of mats to perpetuate for a long period were the most important selection criteria for the single roasting (Plantain) cultivar. Banana producing areas of Rwanda are dominated by high altitudes that are unfavorable to plantain cultivation.

Table 3: *Musa* cultivar diversity (% frequency) distribution by genome groups in Rwanda. Data was collected during a *Musa* germplasm diagnostic survey in 2007. A dash (-) indicates the *Musa* group was not detected in this location in this survey.

Genome groups	% mat frequency of different *Musa* genome groups across districts of Rwanda					
	Total	Kirehe (East)	Bugeresa (East)	Ruhango (Southern)	Karongi (West)	Rusizi (West)
Cavendish (AAA)	1.1	0.0	0.0	3.6	0.2	0
East African highland (AAA)	81.2	86.7	83.0	66.4	96.6	92.6
Other AAAs	6.9	3.0	11.9	10.7	2.5	5.9
AAB plantain	0.8	0.2	3.9	-	-	-
AAB dessert	1.7	7.0	1.3	0.3	0.7	1.4
ABB	6.9	3.1	0	19.1	0.2	0

Cultivar disappearance: Only13% of the respondents reported cultivar loss. The highest perceived cultivar loss was recorded in Bugesera (15%) followed by Rusizi (6%), Ruhango (6%), Kirehe (4%) and Karongi (3%) district. Most affected cultivars included the dessert varieties 'Kamaramasenge' (59%), Gros Michel (38%) and 'Gisukari' (18%) and the ABB beer banana 'Kayinja' (59%). All respondents cited diseases to be responsible for the disappearance of these cultivars.

Table 4: Eigen vectors and values of two principal component axes (PCA) for nine cultivar selection criteria for 4 *Musa* uses groups (beer, cooking, dessert and plantains) in Rwanda in 2007 (Coefficients in bold font indicate most important criteria for each principle component).

Cultivar selection criteria	Beer		Cooking		Dessert		Roasting	
	PC1	PC2	PC1	PC2	PC1	PC2	PC1	PC2
Availability of planting materials	-0.3966	0.0841	-0.3955	0.0877	-0.3961	0.0877	-0.3635	-0.1103
Early maturing	-0.3950	-0.0997	-0.3946	-0.0970	-0.3948	-0.1006	-0.1377	**-0.7377**
Good flavor, taste and high juice yield	-0.1077	**0.5789**	-0.0915	**0.5879**	-0.0900	**0.5863**	-0.3666	0.0406
High market demands / prices	-0.1518	**0.5562**	-0.1724	**0.5449**	-0.1652	**0.5481**	-0.3635	-0.1103
Pests and diseases resistance	-0.3955	-0.0953	-0.3943	-0.0991	-0.3950	-0.0985	-0.3670	0.0136
Size of bunch / big bunch	0.1295	**0.5688**	0.1313	**0.5704**	0.1317	**0.5683**	-0.3635	-0.1103
Long life span of mats	-0.3975	-0.0748	-0.3969	-0.0719	-0.3976	-0.0712	0.2259	**-0.6274**
Tolerance to drought	-0.4005	0.0121	-0.3997	0.0005	-0.4002	0.0163	-0.3670	0.0136
Tolerance to poor soil fertility	-0.4005	-0.0112	-0.3997	-0.0047	-0.4004	-0.0071	-0.3602	0.1537
Eigen values	*6.232*	*2.768*	*6.258*	*2.742*	*6.238*	*2.762*	*7.421*	*1.579*
Percentage variation (%)	*69.24*	*30.76*	*69.54*	*30.46*	*69.31*	*30.69*	*82.46*	*17.54*

DISCUSSION OF RESULTS

Dynamic relative importance of the cultivars and its reasons: Cultivar diversity (richness and evenness) varied across the agro-ecologies of Rwanda and was influenced by the interaction between the agro-ecologies, farmer selection practices and diseases. The variable altitude across Rwanda strongly influences the rainfall amount, temperature conditions and soils, thus influencing the suitability of the districts to the banana crop and the different cultivars. The conditions in high altitudes (low temperature and high rainfall) are conducive for east African high land cultivars (AAA-EA). This could explain dominance of the AAA-EA genome group (66 to 96% of landscape) in the study region (Table 2). Altitude also influences the prevalence of pests and diseases. For example, a high prevalence of banana bunchy top disease, black sigatoka, banana weevils and burrowing nematodes occur at lower altitudes. The presence of moderate to steep slopes at high altitudes makes these sites prone to erosion (van Asten *et al.,* 2004), thus affecting the quality of soils and could as such influence the choice of cultivars to grow. For example, introduced beer banana 'Kayinja' (ABB) is reported to withstand poor soils much better than the AAA- EA bananas (both cooking and beer) (Gaidashova *et al.*, 2005). Higher cultivar diversity was observed in the Eastern districts (Kirehe and Bugesera)

compared to the Western districts (Karongi and Rusizi). The four most predominant cultivars occupied 84% to 88% of the *Musa* production landscape in the western districts compared with 70% to 72% in the Eastern districts (Table 1). The lower diversity in the Western region can be attributed to specialization in the production of a few, yet more productive cultivars for the market. A decline in cultivar diversity was observed in Rusizi district when current data was compared with results from the 2001 *Musa* germplasm survey reported by Nsabimana *et al.* (2008). In this district, banana production is increasingly becoming market-oriented with a special preference for the AAA-EA cooking variety 'Barabeshya' (17% of *Musa* landscape) that possess long fingers (C. Murekezi, Kigali, Rwanda, 2011, personal communication). Barabeshya falls under the AAA-EA Musakala clone set, one of the most commercial groups of East African Highland cultivars. Most (48%) of the 43 *Musa* cultivars in this study were not widely grown and only found in one district (Table 2). Dyke (2008), argues that when a community is dominated by only one or a few species, it may be that the rarer species are at risk being eroded. He further argues that, such a distribution pattern may indicate that the habitat lacks a sufficient diversity of structure, patchiness, or resources to allow many species to exist

together (Dyke, 2008). These cultivars, especially those in insignificant quantities and of no local cultural value could be vulnerable to genetic erosion. An in depth understanding of the community values of the individual cultivars and the conservation *ex-situ* of those of low community importance is therefore recommended. The AAA- EA cultivars 'Bushoki', 'Indundi', 'Umugumira', 'Rumparipfa' and 'Nyirambuye' are not listed among the ISAR Rubona *Musa* accessions. These cultivars were each observed in single districts and could be either synonyms or not yet collected into the ISAR *Musa* collection. There is also the possibility that they are only suited to the specific niches. Morphological characterization and or determination of their synonymy status to cultivars already established at the ISAR collection is recommended. The dominance of beer cultivars in Rwanda (67%) especially in the Western province (71-78% of area under *Musa*), and their declining presence eastwards in favor of cooking banana (Fig. 2) is in agreement with data collected in 2000 by Gaidashova *et al.* (2005). Beer bananas are considered more tolerant to adverse growing conditions, low levels of management and are better suited to regions with low market access (e.g. far from Kigali) because the beer produced has a longer shelf life (Gaidashova *et al.*, 2005). More still, high altitudes (> 1500 masl) support the AAA-EA beer types more than the cooking types (D. Karamura, Kampala, Uganda, 2011, personal communication). However, in the Lake Kivu area (Karongi district) the proportion of the area under beer bananas has declined from 90% (Gaidashova *et al.*, 2005) to 71.5%. This is contrary to previous reports by Gaidashova *et al.*, (2005) who stated that farmers preferred introduced beer bananas (ABB) because they perform better on poor soils than the AAA- EA bananas (both cooking and beer). The high susceptibility of the ABB beer types to Fusarium wilt could have hampered their spread. In addition, the Government of Rwanda's policy of reducing the area under beer banana production (from 60% to 35%) and to increase the area under cooking bananas (from 30% to 45%) and dessert bananas (from 10 to 20%) may be taking root. The dominance of cooking cultivars (60% of

the banana landscape) in Kirehe district is in agreement with previous reports by Bart (1993), Kangasniemi (1998) and Gaidashova *et al.* (2005). Dominance of cooking bananas in this region is attributed to the good soils (Lassoudière *et al.*, 1989) and good access to markets of Kigali (Gaidashova *et al.,* 2005). When comparing results from the present survey with data obtained in 2000 (Gaidashova *et al.*, 2005), the area under dessert bananas has declined by 2 to 3% across Rwanda except in the Kirehe district where production has remained stagnant at 10% (Fig. 2). This could be due to Fusarium wilt that attacks the major dessert type 'Kamaramasenge'. Several cultivars were observed to be of multiple uses to farmers. Most farmers observed that the dessert types helped improve the potency and quality of beer. This partly could explain the multiple uses (beer, dessert and cooking) of some of the cultivars grown in this region.

Pressures and constraints: The pulp or juice taste/flavor/quality; market demand/ price; and bunch size were the most important cultivar selection criteria used by farmers to prioritize cultivars to grow on the farms (Table 4). Cultivars lacking these attributes can be selected against, thus over long periods of farmers' selection; these criteria could greatly influence *Musa* diversity on-farm. On the contrary, ability of *Musa* plants to mature early and the ability of mats to perpetuate for a long period were the most important selection criteria for the roasting cultivars. Banana producing areas of Rwanda are dominated by high altitudes that are unfavorable to plantain cultivation. Only 13% of the respondents reported cultivar loss in the study. Only AAA dessert and ABB 'Kayinja types were reported to be lost. Fusarium wilt is mainly responsible for the loss of the dessert banana varieties ('Kameramasenge', 'Gisukari' and 'Gros Michel') and the ABB beer banana 'Kayinja', while Xanthomonas wilt has devastated numerous plantations with predominantly ABB 'Kayinja' beer types in the Western province of Rwanda. For example, *Musa* ABB beer type 'Kayinja' dominated systems are susceptible to insect mediated floral infections (Addis *et al.*, 2004; Blomme *et al.*, 2005).

CONCLUSION

Cultivar diversity (richness and evenness) varied across the agro-ecologies of Rwanda in addition to being on decline or under threat. Over 48% of the cultivars had a low diversity index and those of local cultural value could be vulnerable to genetic erosion. A decline in cultivar evenness was observed in Rusizi

district previously reported to have higher cultivar evenness. There is likelihood that the Government of Rwanda's policy of crop regionalization is taking root and has an impact on *Musa* diversity. An in depth understanding of the community values of the individual cultivars with low diversity and the conservation *ex-situ*

of those of low community importance is recommended. The study further confirmed the importance of banana beer production in the country, a factor that can promote diversity of beer cultivars in Rwanda. Cooking cultivars however, dominated in the Eastern province district of Kirehe. The study clearly demonstrated that banana cultivar selection in Rwanda is market/end use driven. Taste/flavor, bunch size, and market demand are the most important criteria for banana cultivar selection and thus greatly influence cultivar conservation and distribution on-farm. These criteria are important to follow while breeding or

introducing new materials in this region. Diseases were perceived to greatly contribute to genetic erosion and thus affect *Musa* diversity on-farm. Fusarium wilt is mainly responsible for the loss of the dessert banana varieties (AAB 'Kamaramasenge', AAA-EA Red Banana 'Gisukari' and AAA 'Gros Michel') and the ABB beer banana 'Kayinja', while Xanthomonas wilt has devastated numerous plantations with predominantly beer types in the Western province. Strategies for managing these diseases are critical in the prevention of the genetic erosion of the affected cultivars.

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