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Participatory assessment of potato production constraints and trait preferences in potato cultivar development in Rwanda

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Abstract

Potato (*Solanum tuberosum* L.) is the major food and cash crop in the highland regions of Rwanda. However, farmers are not integrated into the potato breeding process. The objectives of this research were to identify farmers' key potato production constraints and establish preferred traits in potato cultivar development in Rwanda. A participatory rural appraisal (PRA) study was conducted through structured survey involving 144 households and 22 focus groups with 258 participants in Musanze, Gicumbi and Nyamagabe districts. The structured survey used a questionnaire administered to farmers to collect information on importance of potatoes and other main crops. While focus groups discussions used matrix scoring of key production constraints and pair-wise ranking of traits. Potato is the most important food and cash crop, followed by maize, beans and wheat. The dominant potato varieties are Kirundo, Cruza, Mabondo and Victoria. The most important potato production constraints are lack of access to credit, lack of high yielding cultivars, insufficient clean seeds and late blight disease. Variety Mabondo is the most tolerant to late blight, followed by Cruza, Kirundo, Kinigi and Rutuku in all the districts. High yield, disease tolerance and high dry matter content are the most important attributes preferred by farmers. Active farmer participation in early breeding stages is critical for a successful potato breeding programme.

Keywords: Farmers' preferred traits, Participatory rural appraisal, Potato, Rwanda

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1. Introduction

In Africa the area under potato (*Solanum tuberosum* L.) production is about 1.5 million ha with an average yield of 10.8 t ha^{-1} (FAO, 2008). In Rwanda there are approximately 150,000 ha under potato production with an average yield of 11.8 t ha^{-1} (FAOSTAT, 2010). Potato serves as a food and income security source and provides important nutrients. Potato has a high content of carbohydrates, significant amounts of quality protein, and substantial amounts of vitamins, especially vitamin C (FAO, 2008).

In Rwanda, potato is the second major food crop after banana (FAOSTAT, 2010) and its importance is expanding (ISAR, 2008). The highland regions located in southwest and north of the country have the most favourable climatic conditions for potato production (MINAGRI, 2000). These highland regions account for more than 80% of the national potato production, and the remainder is produced in marginal agro-ecologies all over the country (Munyemana and von Oppen, 1999). The major limiting factors to potato productivity in Rwanda include lack of high yielding varieties, diseases, post-harvest losses due to poor handling and storage facilities, insufficient clean potato seed tubers, poor seed distribution system, and inadequate production technologies (ISAR, 2008). Amongst these factors, diseases are the main potato production constraint in Rwanda. The major diseases of potato in Rwanda include late blight caused by *Phytophthora infestans* (Mont.) de Bary, bacterial wilt (*Ralstonia solanacearum* Smith.) and viruses (Kirk et al., 2004; ISAR, 2008; Muhinyuza et al. 2008). Of these diseases, potato late blight is the most serious in the major production zones (Kirk et al., 2004). The disease causes severe yield losses. Disease severity in some fields results in an estimated yield loss of up to 70% (Kirk et al., 2004).

Many studies (Sperling et al., 2001; Ceccarelli and Grando, 2007) on participatory breeding indicated that conventional breeding has not been as beneficial for poor farmers, especially those in marginal areas, because plant breeders did not consider the specific preferences of the farmers. As a consequence, despite many available improved varieties, few are adopted. Farmers for instance still grow unimproved local varieties because officially recommended and released varieties lack the traits of their preference (Witcombe, 2009).

A participatory approach through researcher-farmer interaction and collaboration may increase potato productivity in target environments. Farmers may provide information on varietal preferences, plant types or desired traits to be maintained or introduced (Sperling et al., 2001). Moreira (2006) conducted a case study on participatory maize breeding in Portugal considering parameters defined by small-scale farmers. The author observed increased yield in poly-cropping systems while maintaining the quality traits under a sustainable agricultural system. Previous studies (Ceccarelli et al., 2001; Sperling et al., 2001) demonstrated the importance and efficiency of decentralized participatory selection in identifying promising and high yielding entries at target production environments. These studies established the existence of considerable differences in field selections of lines between breeders and farmers.

Participatory methods consider the value of farmers' knowledge, their preferences, ability and innovation, and their active exchange of information and technologies, as it was demonstrated during farmer field school approach at the international potato research centre (CIP) (Ortiz et al., 2008). In the last decade the participatory research approach in potatoes at CIP has provided a fruitful interaction between farmers and

researchers and promoted learning and innovation (Graham et al., 2001). For example, in Indonesia, farmers guided research on potato cultivation practices linked with integrated pest management (IPM) capacity building through farmer field school, where they were able to learn, interact and implement new technologies together with researchers (Graham et al., 2001). In Peru, farmers managed research on interactions between potato varieties and fungicides within farmer field school. In Bolivia farmers were involved in making crosses and selection in potato (Graham et al., 2001).

Ndolo et al. (2001), reported farmers' involvement at various levels of breeding process in Kenya, where they were involved in evaluating sweet potato varieties and several were selected due to their high yield and wide adaptation, which coincided with the breeders' selection. Devaux and Tegera (1981) attempted participatory approach in Rwanda to involve farmers into potato variety evaluation, but farmers were not fully integrated into the whole breeding process in achieving client-oriented breeding. Plant breeding should actively involve clients in the selection and breeding stages especially during the selection within segregating populations (Gyawali et al., 2007).

Several scientists have emphasized the need for active farmer participation in plant breeding as critical for successful adoption of improved varieties and their production packages (Witcombe et al., 2005; Gyawali et al., 2007). However, the link between research and farmers is still very weak or absent in most developing countries (Ortiz et al., 2008). Information on presently grown varieties, farmers' key production constraints and desired traits in potato cultivar development is inadequate and not well documented in Rwanda. Therefore, the assessment of farmers' knowledge and preferences in cultivar development was undertaken through farmer participatory approaches.

This study was primarily aimed at establishing farmers' knowledge on potato production constraints and their preferred traits for future selection to guide farmer-oriented potato breeding in the country. Therefore, the objectives of this study were to identify and analyse farmer's key constraints in potato production, and establish farmers' preferred traits to be included in cultivar development and variety selection process in Rwanda.

2. Material and methods

2.1. Description of the study areas

The research focused on the highland regions of Rwanda located in north and southwest of the country and covered three main potato growing districts which are Musanze in the highland of volcanic soils, Gicumbi in the Buberuka area, and Nyamagabe within Congo-Nile divide. These regions are the most fertile and productive, and their climatic conditions are well-suited for potato production in Rwanda (Munyemana and von Oppen, 1999). The study areas are located at an altitude between 1800 and 2500 meters above sea level (ISAR, 2008) with a bimodal rainfall pattern with the short and long rains during October to mid-December and March to June, respectively. However, rain is almost always present in these regions and potatoes are

planted throughout the year. In these areas, average annual temperature and rainfall are at 16ºC and 1500 mm, respectively (ISAR, 2008). Table 1 summarizes details of the study areas including altitude, the global positioning system (GPS) coordinates, and the annual rainfall. Major crops cultivated in the regions are potatoes, maize, beans, wheat, peas, vegetables and sorghum (ISAR, 2008).

2.2. Sampling procedures and data collection

2.2.1. Structured survey

A questionnaire was developed and administered to farmers to collect information on farm size, land allocated to potatoes and other main crops, and source of potato seeds. Different administrative levels were considered which included district and village (Table 1). A random sampling involved three districts, twelve villages per district- and four respondents per village. This resulted in a total of three districts, 36 villages, and 144 respondents. Data were gathered using a structured survey questionnaire to get characteristics of the farms and production systems in the districts. Secondary data were collected from previous surveys and reports of national agricultural research institution.

2.2.2. Participatory rural appraisal

A purposive sampling procedure was used to identify the highland regions chosen for their great importance in potato production (Munyemana and von Oppen, 1999). Random sampling was employed to select farmers in each village with the help of the village leaders and extension workers. In each district six to nine villages were selected. This provided a total of three districts and 22 villages. Subsequently 22 focus groups were constituted across the study areas to collect data through focus group discussions. Per village, a focus group composed 10 to 15 representative farmers who had adequate knowledge about the villages, the farms, crops and local conditions and problems in the district. A total of 258 farmers participated in the 22 focus groups in the study areas. Gender balance was taken into account. Using matrix scores and pair-wise ranking, farmers listed and ranked crops grown, advantages of the potato crop in the area, constraints to potato production, potato varieties grown and farmers' preferences, prominent traits to be considered for future improvement and availability of late blight resistant varieties.

During data collection, participatory rural appraisal allowed farmers to express their opinions through group discussions. A checklist was prepared in advance to guide the discussion. Farmers identified preferred traits to be included in selection of potato varieties and expressed their choices and priorities. Pair-wise ranking compared traits of interest pair by pair and groups were asked to choose the preferred one among the two. In matrix scoring, the criteria were placed in rows in a matrix and farmers were asked to give a score from 1 to 10 for each characteristic to complete the matrix; where 1= worse, 2= very poor, 3= poor, 4= somehow poor, 5: fairly good, 6: good, 7: very good, 8: delightful, 9: distinguishable and 10: excellent. The total score was the sum of all the scores given by all the farmers that participated to evaluate the same trait across the row in a matrix. Thus, relatively high scores imply the most important constraints.

Table 1. Physical data of the surveyed area

District	Village	Altitude (m)	Geographical coordinates	Average annual rainfall for the district (mm)
	Butakanyundo	2192	01° 52′251″S and 029° 55′ 296″E	
	Karurambi	2311	01° 54′ 562″S and 029° 53′ 715″E	
	Manjari	2230	01° 54′ 829″S and 029° 54′501″E	
	Nyejoro	2232	01° 44′ 450″S and 029° 58′ 219″E	
Musanze	Kabeza	2456	01° 43′ 803″S and 029° 54′ 050″E	1650
	Rwebeya	2019	01° 27′ 918″S and029° 37′ 022″E	
	Nengo	2155	01° 54′ 135″S and 029° 56′ 398″E	
	Gahanga	2176	01° 55′ 727″S and 029° 55′ 349″E	
	Kabaya	2164	01° 56′ 219″S and 029° 55′ 174″E	
	Mugunzamao	1846	01° 27′ 952″S and 029°39′720″E	
	Kirimbi	2419	02° 24′ 255″S and 029° 23′ 718″E	
Gicumbi	Mugote	1851	01° 45′ 739″S and 030° 00′ 231″E	1200
	Kirenge	2150	01° 61′ 759″S and 030° 01261″E	
	Ryarubuguza	2245	01°61′545″S and 030° 02′ 571″E	
	Akanyirandoli	2187	02° 50′ 756″S and 029° 94′ 893″E	
	Bivumu	2186	02° 50′ 850″S and 029° 48′ 883″E	
	Cyimicanga	2168	02° 50′ 200″S and 029° 49′ 391″E	
	Mujuga	2288	02° 53 ′110″S and 029° 45′ 553″E	
Nyamagabe	Bususuruke	2342	02° 51′ 677″S and 029° 43′ 318″E	1600
	Gashaka	2486	02° 22′ 512″S and 029° 22′ 915″E	
	Uwisuri	2420	02° 24′ 255″S and 029° 23′ 720″E	
	Rwamakara	2442	02° 23′425″S and 029° 23′ 358″E	

Source: ISAR, 2008

2.3. Data analysis

Data collected were analyzed using SPSS (Release15.0) computer package (SPSS Inc., 2006) to obtain descriptive statistics and the GLM procedure in SAS 9.1.2 (SAS Institute, 2004) to calculate analysis of variance and mean comparisons. When significant differences were detected in the ANOVA, mean comparisons were conducted among districts using the least significant test procedure (LSD).

3. Results

3.1. Socio economic benefits of growing potato in the study areas

Farmers indicated various reasons why they are growing potatoes such as its use as both food and cash crop, and a short season crop which can be grown throughout the year. The number of years that potatoes have been grown in the study areas and the number of times they are grown per year are presented in Table 2. It appeared that potato is grown at least twice a year by most farmers. Musanze in the highland regions is the first district where potatoes were grown.

Table 2. Prevalence of potato production obtained through formal surveys in three districts in Rwanda

District	***Number of years potato grown***		***Number of times potato grown per year***		***Size of the largest plot grown with potato (ha)***	
	Mean	*Std. Deviation*	*Mean*	*Std. Deviation*	*Mean*	*Std. Deviation*
Musanze	16.7	11.2	2.7	0.5	1.9	1.9
Gicumbi	10.5	11.3	1.8	0.4	1.7	2.7
Nyamagabe	12.3	8.8	2.2	0.4	1.6	1.8

3.2. Gender composition and decision making in potato production and utilization

An almost equal number of males and females took part in the formal surveys and the focus group discussions (Table 3). Gender involvement in decision making on potato production and utilization is presented in Table 4. Results indicated that both husband and wife are involved in the main potato production activities. They are equally involved in decisions related to planting time, variety to plant,

planting materials, routine crop husbandry, harvesting, transporting and marketing across the study areas. However, some activities such as weeding, cooking, and storage protection are exclusively done by women while predominantly men are totally concerned with pest management.

Table 3. The number of farmers interviewed and gender composition during formal survey and focus group discussions at three districts in Rwanda

District	Male	Female	Total
	Formal survey		
Musanze	25 (52%)	23 (48 %)	48 (33.3%)
Gicumbi	24 (50%)	24 (50%)	48 (33.3%)
Nyamagabe	24 (50%)	24 (50%)	48 (33.3%
Total	**73 (50.7%)**	**71 (49.3%)**	**144 (100%)**
	Focus group discussions		
Musanze	57 (52.8%)	51 (47.2%)	108 (41.9%)
Gicumbi	28 (50%)	28 (50%)	56 (21.7%)
Nyamagabe	46 (48.9%)	48 (51.1%)	94 (36.4%)
Total	**131 (50.8%)**	**127 (49.2%)**	**258 (100%)**

3.3. Economic importance

Focus groups were used to collect general information through discussions. Farmers listed the main food crops they grew in each district and ranked them. Pair-wise ranking was used where farmers were asked to compare the commonly grown food crops. They ranked major crops grown according to their greatest importance as the main food. Major food crops grown by farmers in Musanze, Gicumbi and Nyamagabe districts are presented in Table 5. Potatoes, dry beans and maize are important in all the three districts. Sweet potato is very important in Gicumbi district, important in Nyamagabe district and absent in Musanze district. The main food crops grown across the highland regions are used for home consumption and as important sources of income. Five major cash crops ranked in descending order according to their greatest importance across the study areas are potatoes, wheat, dry beans, vegetables and maize (Table 6).

3.4. Farming systems

3.4.1. Land allocation

The mean land area in hectares allocated to potatoes is higher than for other food crops grown in the study areas. Average land size per household across the highland regions is 1 ha and 0.9 ha of this land area representing about 90% of the total household land are used for cultivation (Table 7). Of the cultivated land 41.5 to 56.3% are allocated to potato production and the rest to other crops (Table 8).

Table 4. Frequency of decision makers on potato production and utilization among 22 focus groups across three districts in Rwanda

Task	Husband	Wife	Husband and wife	Total	Decision maker
Planting time	1	2	**19**	22	Both
Planting materials	9	-	13	22	Both
Variety to plant	3	3	16	22	Both
Weeding	-	11	11	22	Wife
Pest management	12	-	10	22	Husband
Routine crop care	9	8	5	22	Both
Harvesting	-	-	22	22	Both
Transporting	2	-	20	22	Both
Storage protection	1	18	3	22	Wife
Cooking	-	22	-	22	Wife
Marketing	4	-	18	22	Both

3.4.2. Seed source and use of production inputs

The source of seed potatoes in the study areas is presented in Table 9. In the highland regions, most of the farmers acquire seed potatoes from traders (41.2 %) and open market (38.9%). Research institutions and

private companies play a minor role as seed providers and represent only 10.4% and 4.8%, respectively. Few farmers (4.2%) keep their own seeds from their harvests.

Table 5. Pair-wise ranking of major food crops grown among 22 focus groups in Musanze, Gicumbi and Nyamagabe districts in Rwanda

Crop	District[a, b]										
	Musanze (N=9)			***Gicumbi (N=5)***			***Nyamagabe (N=8)***			*Overall*	*Overall*
	Mean	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*mean*	*rank*
Sweet potato	-	-	-	5.2[a]	2.1	2	4.0[b]	4.1	5	4.4	2
Potato	3.3[a]	1.4	1	4.2[ab]	1.8	3	6.7[a]	1.0	1	4.7	1
Dry beans	2.6[a]	1.5	2	5.8[a]	1.1	1	5.0[ab]	3.6	3	4.2	3
Maize	1.5[b]	1.1	3	1.8[cde]	1.1	6	5.1[ab]	1.2	2	2.9	4
Wheat	0.2[cd]	0.6	5	0.0[e]	0.0	10	4.6[b]	1.6	4	1.8	5
Peas	0.0[d]	0.0	8	1.6[cde]	1.8	7	3.5[b]	1.3	6	1.6	6
Sorghum	0.2[cd]	0.6	6	3.0[bc]	3.3	4	1.4[c]	2.5	7	1.2	8
Banana	0.4[cd]	0.8	4	0.6[de]	0.9	8	0.4[c]	1.0	9	0.3	9
Vegetables	1.0[bc]	1.5	7	2.2[bcd]	1.5	5	1.4[c]	1.2	8	1.4	7
Fruits	0.0[d]	0.0	9	0.2[de]	0.4	9	0.2[c]	0.7	10	0.1	12
Cassava	-	-	-	-	-	-	0.2[c]	0.7	11	0.2	10
Soya	-	-	-				0.2[c]	0.4	12	0.2	11
Mean	**1.0**			**2.4**			**2.7**				
LSD	**0.9**			**2.1**			**1.9**				
P value	**0.0001**			**0.0001**			**0.0001**				

[a] *N= number of villages (focus groups) per district that participated in group discussions*

[b] *Means in a column followed by the same letters are not significantly different at P=0.05*

Table 6. Pair-wise ranking of major cash crops grown among 22 focus groups in Musanze, Gicumbi and Nyamagabe districts in Rwanda

Crop	District[a, b]										
	Musanze (N=9)			***Gicumbi (N=5)***			***Nyamagabe (N=8)***			*Overall*	*Overall*
	Mean	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*mean*	*rank*
Sweet potato	-	-	-	2.0^{cde}	2.1	4	1.5^{cde}	2.2	7	1.7	4
Potato	3.0^{a}	1.6	1	5.4^{a}	1.5	1	5.7^{a}	1.4	1	4.5	1
Dry beans	1.5^{b}	1.3	2	4.6^{ab}	0.9	2	0.5^{de}	1.4	9	1.8	3
Vegetables	1.2^{bc}	1.7	3	2.4^{cd}	1.1	3	0.8^{de}	0.8	8	1.3	5
Wheat	0.4^{cd}	1.3	4	1.0^{cde}	2.2	6	4.2^{ab}	2.5	2	1.9	2
Maize	0.4^{cd}	1.3	5	1.4^{cde}	1.5	5	2.1^{cd}	1.7	4	1.3	7
Tea	-	-		0.4^{de}	0.9	9	2.0^{cd}	2.1	5	1.4	6
Fruits	0.1^{d}	0.3	6	-	-		0.1^{e}	0.3	11	0.2	10
Peas	0.0^{d}	0.0	8	0.6^{cde}	0.9	8	2.7^{bc}	1.7	3	1.2	9
Banana	0.1^{d}	0.3	7	1.0^{cde}	1.4	7	0.4^{de}	1.0	10	0.2	11
Sorghum	0.0^{d}	0.0	9	0.0^{e}	0.0	10	1.8^{cde}	2.8	6	1.3	8
Pyrethrum	0.0^{d}	0.0	10	-	-		-	-		0.0	12
Tobacco	0.0^{d}	0.0	11	-	-		-	-		0.0	13
Mean	**0.6**			**1.9**			**2.0**				
LSD	**0.9**			**2.1**			**1.8**				
P value	**0.0001**			**<0.0001**			**<0.0001**				

[a] *N= number of villages (focus groups) per district that participated in group discussions*

[b] *Means in a column followed by the same letters are not significantly different at P=0.05*

Table 7. Mean household farm size and cultivated land in the study areas involving 144 respondents in three districts in Rwanda

District	Total farm size (ha)		Total cultivated land (ha)	
	Mean	*Std. Deviation*	*Mean*	*Std. Deviation*
Musanze	0.8	0.8	0.8	0.8
Gicumbi	0.9	1.3	0.8	1.3
Nyamagabe	1.3	1.4	0.9	0.9
Total	**1.0**	**1.1**	**0.9**	**0.9**

Table 8. Different crops grown and relative importance (%) as income generation and family food use with corresponding land (ha) per household averaged from 144 respondents in Musanze, Gicumbi and Nyamagabe districts in Rwanda

Crop	Income		Food	
	Percentage	*Mean area (ha)*	*Percentage*	*Mean area (ha)*
Potato	56.3	0.5	41.5	0.5
Maize	14.8	0.2	22.9	0.2
Vegetables	2.2	0.1	0.5	0.4
Peas	4.1	0.3	5.3	0.2
Beans	10.5	0.2	19.9	0.2
Wheat	8.7	0.3	4.1	0.3
Sweet potato	2	0.1	3.9	0.2
Bananas	0.1	0.3	0.3	0.3
Sorghum	1.3	0.2	0.3	0.2
Total	**100**	**0.4**	**100**	**0.3**

Table 9. Source of seed potatoes among 144 farmers in Musanze, Gicumbi and Nyamagabe districts in Rwanda

Seed source	Number of farmers	Percentage
Own field	6	4.2
Trader	60	41.7
Open market	56	38.9
Private company	7	4.8
Research institution	15	10.4
Total	**144**	**100**

3.5. Major production constraints

Matrix scoring identified the most important potato production constraints across the study areas as follows: lack of access to credit (mean score: 106.4), lack of high yielding cultivars (99.1), insufficient clean planting materials (92.5) and potato late blight (88.9). The overall matrix score is 65.2 (Table 10). However, access to credit and low yield are not significantly different in Musanze and Nyamagbe districts and are ranked both number one constraints. They are followed by late blight, unclean seeds in Musanze district. Unclean seed is the second major constraint and late blight the third in Nyamagabe district (Table 10). In Gicumbi district, unclean seed is the major production constraint. The second most important constraint in that district is lack of access to credit followed by low yield and poor storage facilities, whereas late blight is among the least important constraints. Other least important constraints identified by farmers across the study areas are dormancy period, low market price, soil degradation, lack of access to fertilizers and fungicides (Table 10).

3.6. Importance of diseases and insects

The major potato diseases reported in the highland regions are presented in Table 11. With the aid of pictures of disease symptoms, farmers recognised the most important diseases occurring on the potato crop. Guided by the moderator, farmers grouped biotic stresses into four categories such as fungal diseases (late blight mainly), bacterial wilt, viral diseases and insect pests. Using pair-wise ranking, fungal diseases (overall mean score = 2.7) is number one biotic stress, bacterial wilt (1.5) second, viral diseases (1.4) third and insect pests (0.4) fourth across the study areas. In Musanze district late blight is the major biotic problem, followed by bacterial wilt, viral diseases and insect pests, while in Gicumbi district bacterial wilt is the main disease affecting potato. In Nyamagabe district, bacterial wilt is the least important disease (Table

11). Farmers reported crop damages (25-50%) caused by late blight, bacterial wilt and viruses' infections on 28.7, 25.5 and 27.7%, of the crops respectively (Table 12). Serious crop damage (>50%) occurred due to bacterial wilt (32%) and late blight (19.2%) while viruses were considered to cause the least damage (Table 12).

Table 10. Matrix scoring of potato production constraints among 22 focus groups in Musanze, Gicumbi and Nyamagabe districts in Rwanda

	District[a, b]							
	Musanze (N= 12)		***Gicumbi (N=12)***		***Nyamagabe (N=12)***		*Overall*	*Overall*
Constraint	*Mean*	*Rank*	*Mean*	*Rank*	*Mean*	*Rank*	*mean*	*rank*
Late Blight	98.8^{ab}	3	55.4^{bc}	5	98.6^{a}	3	88.9	4
Unclean seeds	93.1^{b}	4	100.4^{a}	2	87.0^{ab}	4	92.5	3
Poor storage facilities	53.6^{d}	7	73.6^{b}	3	62.5^{c}	6	61.4	6
Dormancy period	66.0^{cd}	6	32.6^{cd}	8	56.7^{c}	7	55.0	7
Low yield	110.4^{a}	2	72.4^{b}	4	103.0^{a}	1	99.1	2
Low price	75.4^{c}	5	55.2^{bc}	6	66.6^{bc}	5	67.6	5
Lack of fertilizers	21.5^{e}	9	20.6^{d}	9	26.0^{d}	9	22.9	9
Lack of pesticides	17.2^{e}	10	17.4^{d}	10	25.2^{d}	10	20.2	10
inaccessibility to Credit	112.6^{a}	1	104.0^{a}	1	100.8^{a}	2	106.4	1
Soil degradation	26.8^{e}	8	39.0^{cd}	7	49.4^{c}	8	37.8	8
Mean	**67.6**		**57.1**		**67.6**		**65.2**	
LSD	**17.0**		**24.1**		**22.5**			
CV (%)	**26.8**		**33.1**		**33.3**			
P-value	**<0.0001**		**<0.0001**		**<0.0001**			

[a] N= Average number of farmers per village (focus group) per district that participated in group discussions

[b] Means in a column followed by the same letters are not significantly different at P= 0.05

Table 11. Pair-wise ranking of major potato diseases and pests involving 22 focus groups across three districts in Rwanda

	District[a, b]							
	Musanze (N=9)		Gicumbi (N=5)		Nyamagabe (N=8)		Overall	Overall
Disease/pest	*Mean*	*Rank*	*Mean*	*Rank*	*Mean*	*Rank*	*mean*	*rank*
Late blight	3.0[a]	1	2.0[b]	2	3.0[a]	1	2.7	1
Bacterial wilt	2.0[b]	2	3.0[a]	1	.0[d]	4	1.5	2
Viral diseases	1.0[c]	3	1.0[c]	3	2.0[b]	2	1.4	3
Insect pests	0.0[d]	4	0.0[d]	4	1.0[c]	3	0.4	4
Overall Mean	**1.5**		**1.5**		**1.5**			

[a] N= number of villages (focus groups) per district that participated in group discussions

[b] Means in a column followed by the same letters are not significantly different at P= 0.05

3.7. Farmers-preferred varieties and traits

3.7.1. Potato varieties grown in the study areas

Potato varieties grown in the study areas are presented in Table 13. There were significant (P<0.0001) differences between villages per district and between districts in terms of the kind and number of potato varieties grown. Varieties Kirundo, Cruza, Mabondo, Victoria, Gikungu and Sagema are grown in all the three districts. Using pair-wise ranking the dominant varieties across the study areas are Kirundo (mean score = 2.6), Cruza (2.2), Mabondo (1.8) and Victoria (1.1). In Musanze district the most important varieties grown by farmers are Kinigi (mean = 4.2), Petero (4.0), Kirundo (3.4), Mabondo (2.8) and Cruza (1.5). In Gicumbi district, most important varieties include Rutuku (mean = 4.8), Kirundo (3.6), Mabondo (2.4) and Cruza (1.4). Rutuku is a given name to any of the red skin varieties. It could be probably Kinigi, Victoria or Gikungu which are the most important red varieties available in the region. In Nyamagabe district, Cruza (mean = 3.4) is significantly different from the others. It is followed by Locale (mean= 1.4), Kirundo (1.1) and Victoria (1.1).

3.7.2. Late blight tolerant varieties in the highland regions

Pair-wise ranking of varieties according to reaction to late blight is presented in Table 14. Mabondo is the most tolerant varieties (mean score = 2.7), followed by Cruza (2.5) and Kirundo (1.7) in the regions. However, Kinigi is the most tolerant variety in Musanze district and Rutuku is the most tolerant in Gicumbi while Cruza is the best in late blight tolerance in Nyamagabe district. In each district the three most tolerant cultivars are ranked as follows: Kinigi (mean score = 5.8), Mabondo (3.6) and Kirundo (2.6) in Musanze district. In Bicumbi district, Rutuku (4.6) is the most tolerant variety followed by Cruza (4.2) and Mabondo (2.8) is the third. In Nyamagabe district the ranking is as follows: Cruza (2.1), Locale (1.6), and Mabondo (1.5).

Table 12. Crop damage levels (%) due to potato diseases reported by 144 farmers in Musanze, Gicumbi and Nyamagabe districts in Rwanda

Type of damage	**Late blight**	**Bacterial wilt**	**Viruses**
Complete crop loss	9.2	5.7	5.8
Serious damage(50%+)	19.2	32	14.6
Important damage (25-50%)	28.7	25.5	27.7
Non-important damage (<25%)	30.7	25.2	37.4
No damage at all	12.3	11.7	14.6
Total	**100**	**100**	**100**

3.7.3. Farmers-preferred potato traits

Through pair-wise ranking high yield (mean score = 4.2), disease tolerance (3.5) and high dry matter content (3.4) were identified by famers as the most preferred attributes across the regions (Table 15). The three characteristics: high yield (mean score = 4.0), disease tolerance (3.4) and high dry matter content (3.7) are not significantly different from each other in importance in Musanze district and also in Bicumbi district where high yield (4.6), disease tolerance (3.4) and dry matter content (3.8) are not significantly different from each other. The traits are equally important in the two districts. But in Nyamagabe district, they are significantly different from each other where high yield (mean score = 4.1) was the most important trait, followed by disease tolerance (3.7) and then high dry matter content (2.6) (Table 15). Early maturity (overall mean score = 2.0), dormancy period (1.2) (Table 15) marketability, tolerance to poor soil, big tuber size with round shape (Table 16) are also important attributes considered by famers across the study areas.

4. Discussion and conclusion

The present study confirmed that potato is an important food security crop in Rwanda. The study revealed that both women and men are equally involved in decision making in the main activities of potato production and utilization. The PRA established that potato is the most important food crop and an important source of income in the study areas. Other major crops cultivated in the regions are, maize, beans, wheat, peas, vegetables and sorghum. These food crops are used for home consumption and also as important sources of income.

Table 13. Pair-wise ranking of potato varieties grown in Musanze, Gicumbi and Nyamagabe districts among 22 focus groups

	District[a, b]									Overall	Overall
	Musanze (N=9)			*Gicumbi (N=5)*			*Nyamagabe (N=8)*			Mean	rank
Variety	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*		
Cruza	1.5^{bcd}	2.3	7	1.4^{bc}	1.7	4	3.4^{a}	1.4	1	2.2	5
Mabondo	2.8^{abc}	2.2	4	2.4^{abc}	3.2	3	0.4^{bc}	0.7	7	1.8	6
Makoroni	1.2^{cd}	1.7	9	1.2^{bc}	1.6	6	-	-	-	1.2	9
Kirundo	3.4^{ab}	2.4	3	3.6^{ab}	3.3	2	1.1^{bc}	2	3	2.6	4
Victoria	1.0^{cd}	2.3	10	1.2^{bc}	1.6	5	1.1^{bc}	1.8	4	1.1	12
Gikungu	0.6^{d}	2	14	1.2^{bc}	2.7	7	0.4^{bc}	1.1	8	0.7	17
Sangema	0.0^{d}	0	15	0.4^{b}	0.9	10	0.8^{bc}	1.6	5	0.4	20
Petero	4.0^{a}	3.5	2	-	-	-	-	-	-	4	3
Kinigi	4.2^{a}	2.5	1	-	-	-	-	-	-	4.2	2
Nyirakabondo	0.8^{cd}	1.7	12	-	-	-	-	-	-	0.9	14
Nyabizi	1.6^{bcd}	1.1	6	-	-	-	-	-	-	1.6	7
Bineza	1.0^{cd}	1.6	11	-	-	-	-	-	-	1	13
IPP	0.7^{d}	2.3	13	-	-	-	-	-	-	0.7	16
Kigega	1.8^{bcd}	2.5	5	-	-	-	0.2^{bc}	0.7	9	1.1	11
Rwishaki	1.2^{cd}	2.5	8	-	-	-	-	-	-	1.2	10
Rutuku	-	-	-	4.8^{a}	1.5	1	-	-	-	4.8	1
Mbumbe	-	-	-	0.2^{b}	0.4	12	-	-	-	0.2	22
Nderera	-	-	-	0.4^{b}	0.9	11	-	-	-	0.4	21
Mizero	-	-	-	0.8^{b}	1.7	8	-	-	-	0.8	15
Makerere	-	-	-	0.6^{b}	1.3	9	-	-	-	0.6	18
Gasore	-	-	-	-	-	-	0.1^{c}	0.3	10	0.1	23
Nyirangeli	-	-	-	-	-	-	0.0^{c}	0	11	0	24
Locale	-	-	-	-	-	-	1.4^{b}	1.8	2	1.4	8

	District[a, b]									Overall	Overall
	Musanze (N=9)			*Gicumbi (N=5)*			*Nyamagabe (N=8)*			Mean	rank
Variety	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*		
Mugogo	-	-	-	-	-	-	0.5^{bc}	1.1	6	0.5	19
Kenya	-	-	-	-	-	-	0.0^{c}	0	12	0	25
Mean	**1.7**			**1.5**			**0.8**				
P-value	**0.0004**			**0.01**			**<0.0001**				
LSD (0.05)	**2**			**2.5**			**1.2**				

[a] *N= number of villages per district that participated in group discussions*

[b] *Means in a column followed by the same letters are not significantly different at P= 0.05*

Table 14. Pair-wise ranking of late blight tolerant varieties in the study areas among 22 focus groups

	District[a, b]									Overall	Overall
	Musanze (N=9)			*Gicumbi (N=5)*			*Nyamagabe (N=8)*			Overall	rank
Variety	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	mean	
Mabondo	3.6^{b}	2.8	2	2.8^{abc}	3	3	1.5^{abc}	1.69	3	2.7	3
Cruza	1.9^{bcde}	2.9	6	4.2^{ab}	3.2	2	2.1^{a}	1.55	1	2.5	4
Kirundo	2.6^{bc}	1.6	4	2.0^{bcd}	2.4	4	0.6^{bcd}	0.74	8	1.7	8
Victoria	1.0^{cde}	2	10	0.0^{d}	0	10	0.7^{bcd}	1.16	6	0.7	16
Sangema	0.0^{e}	0	15	0.2^{d}	0.4	9	0.8^{abcd}	1.64	4	0.4	18
Gikungu	0.6^{de}	2	12	1.0^{cd}	2.2	6	0.6^{bcd}	1.76	9	0.7	14
Kigega	1.1^{cde}	1.7	9	-	-	-	0.2^{cd}	0.71	10	0.7	15
Makoroni	2.8^{bc}	2.8	3	1.8^{bcd}	1.3	5	-	-	-	2.4	5
Kinigi	5.8^{a}	1.3	1	-	-	-	-	-	-	5.8	1
Petero	2.1^{bcd}	2.9	5	-	-	-	-	-	-	2.1	6
Nyirakabondo	0.9^{bcde}	0.8	11	-	-	-	-	-	-	0.9	11
Bineza	1.9^{bcde}	2.6	7	-	-	-	-	-	-	1.9	7
Nyabizi	0.2^{de}	0.4	14	-	-	-	-	-	-	0.2	20
IPP	0.3^{de}	1	13	-	-	-				0.3	19
Rwishaki	1.1^{cde}	2.3	8	-	-	-	-	-	-	1.1	10
Rutuku	-	-	-	4.6^{a}	1.6	1	-	-	-	4.6	2
Makerere	-	-	-	0.0^{d}	0	11	-	-	-	0	23
Nderera	-	-	-	0.8^{cd}	1.8	7	-	-	-	0.8	12

	District[a, b]										Overall
	Musanze (N=9)			*Gicumbi (N=5)*			*Nyamagabe (N=8)*			Overall	rank
Variety	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	**mean**	
Mizero	-	-	-	0.6[cd]	1.3	8	-	-	-	0.6	17
Gasore	-	-	-				0.7[bcd]	2.1	7	0.7	13
Mugogo	-	-	-	-	-	-	0.0[d]	0	13	0	24
Nyirangeli	-	-	-	-	-	-	0.1[d]	0.3	11	0.1	21
Locale	-	-	-	-	-	-	1.6[ab]	1.8	2	1.6	9
Kenya	-	-	-	-	-	-	0.1[d]	0.3	12	0.1	22
Mean	**1.7**			**1.6**			**0.8**				
P-value	**<0.0001**			**0.001**			**0.04**				
LSD (0.05)	**1.9**			**2.4**			**1.3**				

[a] *N= number of villages (focus groups) per district that participated in group discussions*

[b] *Means in a column followed by the same letters are not significantly different at P= 0.05*

Table 15. Pair-wise ranking of farmers-preferred potato characteristics in the study areas among 22 focus groups

	District[a, b]										
	Musanze (N=9)			**Gicumbi (N=5)**			**Nyamagabe (N=8)**				
Characteristics	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Overall Mean*	*Overallr ank*
High yield	4.0[a]	1.2	1	4.6[a]	0.5	1	4.1[a]	1.1	1	4.2	1
Disease resistance	3.4[a]	1.0	1	3.4[a]	0.5	1	3.7[ab]	0.8	2	3.5	2
Good taste	0.4[c]	0.7	4	0.8[b]	1.3	2	0.5[d]	0.9	6	0.6	6
Short dormancy	1.1[bc]	0.9	3	0.8[b]	0.8	2	1.6[cd]	1.4	4	1.2	5

	District[a, b]										
	Musanze (N=9)			Gicumbi (N=5)			Nyamagabe (N=8)				
Characteristics	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Mean*	*SD*	*Rank*	*Overall Mean*	*Overallr ank*
Early Maturity	2.1[b]	0.9	2	2.0[b]	1.2	2	2.0[c]	0.5	5	2.0	4
High dry matter content	3.7[a]	1.4	1	3.8[a]	1.3	1	2.6[bc]	1.6	3	3.4	3
Mean	**2.5**			**2.6**			**2.4**				
LSD	**1.0**			**1.3**			**1.1**				
P value	**<0.0001**			**<0.001**			**<0.001**				
CV(%)	**42.6**			**39.6**			**46.6**				

[a] *N= number of villages (focus groups) per district that participated in group discussions*

[b] *Means in a column followed by the same letters are not significantly different at P= 0.05*

Table 16. Advantages and disadvantages of the most grown varieties as presented by key informants involving village leaders and extension workers in the study areas

Varieties grown	***District***	***Advantages***	***Disadvantages***
Kinigi, Kirundo, Rutuku and Mabondo	Musanze, Gicumbi and Nyamagabe	- High yielding - High dry matter content - Marketability - Tolerance to late blight	- Susceptible to bacterial wilt

Varieties grown	*District*	*Advantages*	*Disadvantages*
		- Big tuber size and round shape	
Petero	Musanze	- High yielding - High dry matter content	- Susceptible to diseases
Cruza	Musanze, Gicumbi and Nyamagabe	- High yielding - High tolerance to diseases - Tolerance to poor soil (acidic)	- Low dry matter content - small-to medium tuber size - Late maturity
Locale	Nyamagabe	- Resistance to diseases	- Late maturity - Small tuber size - Low yield
Victoria	Musanze, Gicumbi and Nyamagabe	- High yielding - Big tuber size and good shape (Round) - Early maturity	- Susceptible to diseases - Low dry matter content

Landholdings are very small as Rwanda is one of the most densely populated countries in the world with 430.6 persons km^{-2} of land area (World Bank, 2011). The average land size is 1.0 ha per farmer with more than 50% of that land allocated to potato production. Potato is the principal crop in the study areas and inoculum of *Phytophthora. infestans*, the causal agent of late blight, is always present due to continuous cropping and conducive conditions for late blight occurrence and spread in the highland regions (Muhinyuza et al. 2008). The survey showed that the sources of potato planting materials are mainly traders and open market whereas research institutions and private companies play a minor role as seed providers. It is clear that farmers do not have access to clean seeds, which may lead to high incidence and severity of important diseases in the regions. The use of infected planting materials is a common way of disease spread in potatoes. Selection and use of clean planting materials could reduce incidence and severity of important diseases.

Major potato production constraints include lack of access to credit, lack of high yielding cultivars, insufficient clean planting materials, late blight, dormancy period, low market price, soil degradation, inaccessibility to fertilizers and fungicides. Serious crop damage occurs due to late blight, bacterial wilt and viruses while insect pests are considered to cause less damage in the study areas. However, late blight is the

most important disease in the potato areas of Rwanda as it was stated previously by different authors (Kirk et al. 2004; ISAR, 2008, Muhinyuza et al. 2008).

Pair-wise ranking established that the most important potato varieties grown in the three districts covered by the study are Kirundo, Cruza, Mabondo, Victoria, Gikungu and Sagema. However, 24 different potato varieties were recorded in the study areas. Although some of these varieties are susceptible to late blight, high levels of genetic variability exist within the different varieties. Using pair-wise ranking, farmers established late blight tolerant varieties across the study areas. Mabondo is considered the most tolerant variety across the districts, followed by Cruza and Kirundo. However, Kinigi is considered the most tolerant variety in Musanze district and Rutuku the most tolerant in Gicumbi while Cruza is considered the most late blight tolerance in Nyamagabe district. Moreover, Nyirakabondo, Victoria, Makerere are considered the least tolerant varieties in Musanze, Nyamagabe and Gicumbi, respectively. These results were consistent with previous reports that Cruza, Kinigi and Mabondo are the most potato tolerant varieties while Victoria is the least tolerant following many years of testing in ISAR (ISAR, 2008).

Pair-wise ranking indicated that high yield, disease tolerance and high dry matter content are the most important attributes preferred by farmers across the regions. Moreover, early maturity and short dormancy period, marketability, tolerance to poor soil, big tuber size with round shape are also important attributes considered by famers across the study areas.

Results from this research indicated that potato breeding should actively involve farmers in the selection and breeding processes, especially during the early selection generations for a successful potato breeding programme. Active farmer participation in plant breeding is critical in selection and breeding stages for successful adoption of improved potato varieties. Farmers indicated that they need varieties with high yield, disease tolerance and high dry matter content. Therefore, in the future, when selecting and breeding new varieties, farmers should be actively involved to ensure the development of varieties that include farmers' preferences.

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