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# Morphological characterisation of sorghum (*Sorghum bicolor*) diversity in Burundi.

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# Abstract

Sorghum (*Sorghum bicolor* (L.)Moench), is a cereal crop close to maize and sugar cane. The crop originated in the Northeast part of Africa and has been an important crop in many dry areas of tropical countries. Sorghum is used for beverage and porridge for many people of Africa. Although sorghum is socially still an important cereal in Burundi, few studies have been undertaken on that crop. In a biodiversity management context, this study on sorghum was therefore set to characterize fifty landraces collected from seven provinces of Burundi and evaluated through morphological traits in two sites. The objectives of this study were to assess the phenotypic diversity and compare the pattern of distribution among landraces according to the ecological zones.

Five quantitative and sixteen qualitative traits were considered separately during the statistical analysis. Cluster analysis based on quantitative traits showed a wide range of diversity in the fifty sorghum landraces independently of the provinces of collection. However, in some cases the distinct groups of sorghum were related to the ecological zones of origin. Burundi landraces were mainly red and brown in the seed colour, that may result from the use for traditional beverage while white seed cultivars were very few and concentrated to three provinces. All the cultivars had panicles which varied from semi loose and dropping to compact elliptic and this confirms the predominance of Caudatum - Bicolor race. The analysis of variance detected highly significant differences among the sites for the five quantitative characters studied.

The pattern of morphological variation is suggested to be assessed in fields under traditional cultivation system. An implementation of strategies for in situ and ex situ conservation is recommended to protect this sorghum diversity, currently neglected and threatened by genetic erosion.


Keys words: Burundi, landraces, morphological traits, variability, *Sorghum bicolor*.

# Contents

# Introduction

## Crop description

Sorghum [*Sorghum bicolor* (L.) Moench] is a cereal crop similar to maize and closely related to sugar cane. Some studies have recently confirmed the strong similarity of the sorghum and sugar cane genomes. Sorghum belongs to the Poaceae family and the tribe of Andropogoneae (Harlan & de Wet, 1972). It has been argued that the Andropogoneae tribe has a centre of variability in the Katanga (Congo) region of tropical Africa. Compared to maize, sorghum has a thin stem which can have tillers and more finely branched roots. The height of cultivated varieties varies from 0.5 m to 6 m. According to the inflorescence (panicle), which varies from very open and loose to very compact, cultivated sorghum have been classified into five races (Bicolor, Guinea, Caudatum, Durra and Kafir) and ten intermediate races corresponding to the pair wise combinations of major races. They are identified according to morphological traits, especially panicle, grain and glume traits (Harlan & de Wet, 1972). The determination of the degree of expression of those traits and their combinations are still subjective and has made the sorghum race identification more complicated. Sorghum taxonomy has been a subject of many modifications since it was described by Linnaeus in 1753. First by Snowden in 1936 followed by Harlan and de Wet in 1972 and until now sorghum classification has been complex for most of the new scientists. However, sorghum identification can rather easily be carried out in the field for familiar researchers or in the laboratory from head or even spikeless specimens (ICRISAT, 2008). The principal colours of sorghum grains are white, red, brown, orange and yellow with a range of intermediate colours. In addition to cultivated sorghum, there is a number of wild and weed sorghum species.

Fig. 1. Sorghum field in Burundi. Photo: Espérance H. 2005

## Importance of the crop

Sorghum has been domesticated since approximately 3000 years B.C. in the Ethiopia region (Ayana & Bekele, 1998) and parts of Congo, with secondary centres of origin in India, Sudan and Nigeria, where it is mainly used for human food (Berenji et al., 2004). The crop is found in tropical and subtropical countries of the world. Sorghum is the fifth cereal grown worldwide in terms of both production and area planted (FAO, 2004). Several studies on sorghum have concluded that it can successfully survive in semi arid areas, which are too dry or too hot for maize. Its waxy leaves that curl during moisture stress help the plant to be more drought tolerant. In addition to tolerating natural stress, temperature and water stress, the crop adapts well to varied soil types and toxicities. These factors together make it an ideal crop for growing in stressful environments.

This spring cereal is known for the nutritious value of its grains (71 percent of starch, ten percent of proteins and three percent of lipids), which is similar to other cereals (Medraoui et al., 2007).

Table 1. Comparison of energy and protein levels for sorghum and maize (as feed).

| | Metabolisable energy for ruminants(MJ/kg) | Metabolisable energy for poultry(MJ/kg) | Protein content (%) | Lysine content (%) | Available lysine content (%) |
|---|---|---|---|---|---|
| Sorghum | 12,4 | 13,7 | 11,0 | 0,27 | 0,19 |
| Maize | 12,1 | 14,2 | 9,0 | 0,27 | 0,22 |

In comparison to maize, sorghum has acceptable levels of protein and energy needed in animal feeding (FAO, 2007). However, for human nutrition, sorghum grain is poor in lysine and threonine and the deficiency in these amino acids is one of the origins of the chronic malnutrition problems among children in Sub Saharan Africa (FAO, 2001). The brown and red grains have higher content in tannins and has a soft and white endosperm and are not palatable to birds at milky or dough stage. New research in sorghum has come up with new varieties without tannins in the grains. White sorghum flour mixed at low percentage with other cereal flour can be used in cakes and biscuits (unpublished).

Not only in Africa, Sorghum is still an important staple food in south Asia and Central America, and it has been placed as a major cereal crop after wheat, rice, maize and barley (FAO, 2006). In developing countries, sorghum is consumed in the form of porridge, as a steam-cooked product, such as couscous, or as a traditional alcohol or non–alcohol beverage. Some African countries have widened the utilization of sorghum into the brewery industries. In USA and Australia, people mainly use sorghum as animal feed and more recently, with research on bio-energy products; sorghum is becoming a multipurpose crop for food, fodder and fuel (Belum, 2007). Environmental issues and fuel cost considerations have come up with the idea of using alternative raw material for ethanol production. Less demanding, compared to maize, sorghum could be used in the bio fuel production without constraining the world food market. Nowadays, it is stipulated that sweet sorghum could be an ideal solution for bio fuel and many studies are going on and using many aspects to increase the biomass production of sweet varieties. In 1985, Neal reported that a high biomass was associated to high percentage of readily fermentable sugars and combustible fiber and consequently research on biomass production was needed to understand how to manage the many factors associated with maximizing total plant production.

In Europe, sorghum is still considered as the 'poor farmer's crop' of Africa and Asia, and very limited research efforts have been undertaken to improve the crop for European conditions (Berenji & Dahlberg, 2004). In the few studies on sorghum, it was found that sorghum can be grown in southern Europe, precisely in Mediterranean areas. Sorghum appeared in southern France in the 1970's and was essentially used for animal feed. In 2008 it was recognized that the cultivation area in France was increasing and the principal buyer of European sorghum was Spain, where sorghum is recommended in the pig production.

Concerning research, some scientists have been successfully working to improve sorghum production and one of the Research Centres, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), located in India, serves as a world centre for improving sorghum grain yield and quality. ICRISAT holds more than 36 000 accessions of sorghum from a number of countries (ICRISAT, 2008). Compared to rice, wheat and maize, little research has been done on sorghum. The ongoing environmental changes associated with the ability of sorghum to grow in unsuitable areas for others crops, may bring more attention and increase the research action on sorghum. Considerable research and improvements are needed and expected. Diversity analysis is a preliminary study to come up with real basic need for better understanding. Research has been oriented on variety studies and diversity assessment in sorghum to identify cultivars with good organic component like low tannin content, drought tolerance and weed resistance. In Africa, a number of studies have been focusing on crop diversity analysis and how different crops are used. A high level of diversity was reported in sorghum from Ethiopia (Ayana & Bekele, 1998). Nevertheless such work on the sorghum diversity has not yet been carried out in Burundi and this master thesis project could be the starting point to be completed in the future by genetic analysis.

## Context and Objectives of the study.

Agro biological diversity, known as genetic resources for food and agriculture, contains more than 7 000 food species (Wilson, 1992). However less than 50 species are used to meet 95 percent of the world's food energy needs (FAO, 1996) while the rest of the species are underutilized for human nutrition purposes. The traditional farming systems used a high crop diversity of adapted landraces. In developing countries of Africa, current agricultural policies advocate homogeneous crops with high yield and unconsciously marginalize the high species diversity found in small scale farming. With this decline of crop diversity in households, some landraces are subject to serious genetic losses due to massive introduction of monoculture (Brown, 1983) and the related local knowledge is threatened to disappear. However, landraces result from ongoing evolutionary processes of domestication in agricultural systems where farmers continue to select their seeds and farmers' practice strongly affect and influence these loss processes (Adeline et al., 2007).

### Agro biodiversity in Burundi.

In Burundi, like in many other developing countries, agriculture is still dominated by subsistence farming which is based on mixed crop and livestock production and agro forestry systems (FAO, 2004). Agriculture is predominated by beans, maize, banana, sweet potatoes, potatoes and cassava. Traditional small farmers keep their seeds from the previous harvested crop using the traditional bulk selection method. There is no consideration concerning diversity management in cultivated crop species in traditional farming. From one year to the next, farmer will always cultivate some landraces while omitting others, according to individual preferences (Adeline et al., 2007).

From that perspective, there is an urgent need to assess and conserve genetic diversity in the agro biodiversity sector. In Sub Saharan countries, several indigenous food crop landraces contribute significantly in food security due to their local environmental adaptation. They are an important complement to certain improved crops which require high agricultural inputs. With time, indigenous knowledge in terms of conservation and utilization of local crops are getting lost and some species are under threat. However, plant genetic resources less identified, less protected and less utilized will be useful for present and future generations. Burundi is facing food insecurity due to social conflicts, climatic changes (drought, rain irregularity), decrease of soil fertility and high population density, with more than 90 percent of the population being traditional farmers.

To overcome all these problems, the country is planning to increase the agricultural production with modern agricultural techniques, water and other available natural resources. In terms of plant diversity, less information, data and plant material are available regarding collection, characterization and conservation. Limited human resources are trained in these areas.

### Sorghum state in Burundi

Sorghum ("Amasaka" or "Amahonda" in local language) is nowadays a neglected crop in many areas of Burundi, except in Kirundo, an important province concerning sorghum cultivation where it is still extensively grown, despite the short rainy season in this area. Compared to other local cereal crops like maize, wheat and rice, which are cultivated on a large scale to meet the high market demand; the cultivation area of sorghum is decreasing. Furthermore, sorghum was the main cereal crop during the 1960's, and it is found in the middle of the Burundi flag together with a drum (symbols of the kingdom). Socially important, sorghum beer is used in many public ceremonies (wedding, death, birth, and visit). Nowadays, it is ranked second after maize and before rice in terms of production (FAO, 2007). In addition to traditional use for local beer and porridge, the national brewery industry used to buy sorghum grain to make industrial beer. But during the social crises period of 1993 up to 2005, the brewery industry like other local companies was not working well and stopped the production.

The impact of social conflicts and war on biodiversity is high but not always directly perceptible (habitat destruction, pollution, local species extinction). The impact may last for a long time and many local crop diversity losses are irreversible. Due to the conflicts, which shook the country, most of the farmers had to move from their farms. A large proportion of the displaced rural population, mainly small scale farmers, who usually keep a large number of crop diversity in their farms; were relocated to urban and peri - urban areas for their security. The massive relocation of the population had a direct impact on the natural and crop resources. Due to the difficult conditions, the immediate need was to help human suffering and provide feeding assistance. Therefore the biodiversity conservation issues were of no interest for the parties in conflict, the government or the humanitary partners.

In Burundi, the impact on sorghum cultivation was related to the loss of the farmer's seed conservation and the national gene bank losses (electricity problem, insecurity, lack of personnel and information). Donors often tend to withdraw their financial support when a conflict breaks out. At ISABU, the sorghum research program suffered from lack of funds from foreign donors, just like other research programmes in the country. Those phenomena (displacement due to war situation and research funds) together caused diversity losses in the country as well as reduction of research staff working on sorghum. Without good sorghum seeds from the research centre, degeneration of cultivated sorghum varieties was observed.

As a part of a rehabilitation of biodiversity conservation, a recent collection of sorghum varieties has been made across Burundi provinces by ISABU in 2006. Only 53 varieties were obtained compared to 140 accessions collected in 1982 and received by ICRISAT in 1983. Within twenty years, Burundi has lost approximately more than 50 percent of the sorghum diversity. Not only sorghum, a large number of the Burundi crop diversity has disappeared during the war period. From 1993 up to now, most of the farmers moved to urban areas and are not living in the same place to grow crops with their local traditional knowledge as they were used to do before the war. For the small proportion of population who returned to their farms, they had to buy new crop varieties (usually as monovarietal seeds) from markets to start the production process in their fields again, while their crop landraces and traditional local resources had disappeared.

Concerning the utilization of sorghum in Burundi, beer production seems to be the most dominant product even though there are no true figures to confirm the statement. Most of Burundi sorghum landraces are brown or red-seeded cultivars with high content of tannins. But using local knowledge Burundians know how to eliminate the effects of tannins to human health. They mix sorghum grains with ash for 24 hours and then clean them before germination. Before the war, there was a big nutrition project "MUSALAC" established by the Musaga health council in 1985 for making composite flour with high nutritive value with complete meal for all ages. The mixture which contained 35 percent of sorghum, 30 percent of maize, 20 percent of soybean, ten percent of sugar and five percent of powder milk. The product was intended to rehabilitate malnourished children and was also meant to be more widely marketed in order to prevent malnutrition more generally. For reasons of digestibility, it is only recommended for children over six months. Due to provision problems the project couldn't go on and only one sub unit in Muyinga is still functioning out of five original units in the country. There is a hope that the National Centre of Food Processing (CNTA) is starting functioning and will use many available local crops.

In addition to the impact of socio political crises on agro biodiversity, a number of factors have contributed to the declining of sorghum cultivation area and sorghum diversity. Research on sorghum in ISABU (Institut des Sciences Agronomiques du Burundi) started in 1954 when the research station of Moso was created and activities extended to the lowland of Imbo and then at Murongwe and Kirundo in the middle altitude zones and finally at Munanira and Mahwa for highland area. The altitude of those locations varies from 830 m to 2 100 m above sea level and this show the ability of sorghum to produce over a high altitudinal range. The consequence of lack of research funds was a reduction of researchers working on sorghum and actually one person was affected in that program, to generate technologies and evaluate them in rural fields together with extension officers and farmers who would select what was convenient for them.

Further analysis could show that sorghum is facing other problems, such as climate changes. Burundi has one of the fastest growing populations in Africa and the population pressure causes changes in land use and environmental and soil fertility degradation. Compared to maize, sorghum has a long vegetative cycle of six months in most of the cultivation zones of the high land in the country. With such a long growth period the fields are occupied for a long time with the uncertainty of harvest since the rainy seasons are becoming shorter than before. The small farmers will keep short duration and cash crops to minimise the risk of food shortage for the family. Moreover, most of African families count more than ten individuals and to get enough food is a problem in many cases. With the demographic pressure and problems in the land use, people lack enough grazing area for their cattle; therefore there is a negative impact on soil fertility.

To all those factors which are playing a big role in the reduction of sorghum cultivation areas in Burundi, we should add damages from birds. The red-billed Quelea (*Quelea quelea*), called also "pest bird" is a famous bird of Sub Saharan Africa with high populations which can devastate cereal fields. Quelea problem is an important criterion for farmers to reject white sorghum varieties without tannin. There is also uncontrolled grazing of fields by domestic animals, also not negligible. Other abiotic constraints are related to ecological zones and climate, were wind, water deficit and low temperature are important in several parts of the country. There are some biotic constraints of diseases which cause high losses in sorghum cultivation (stem borer, cercosporiose). In that context sorghum production usually used for porridge or traditional beer, may not be a priority, resulting in abandonment and reduction in sorghum cultivation. This is observed in many regions of the country and then sorghum diversity is threatened as well.

All those observations and factors developed above have led to that the crop has become neglected and extinct in some provinces. In perspective of preserving biodiversity, the present project and master thesis data could lead to the development of a warning system in sorghum loss in Burundi. The principal objective of the present research project is to carry out a study on collected landraces for more information on the variability among sorghum diversity found in the country. Analyzing the diversity of sorghum and the geographical distribution in Burundi, could be a valuable start for an in situ and ex situ germplasm conservation programme. At the same time the diversity analysis could be very important as a research starting point to increase the tools and the skills for the sorghum breeding program at ISABU, which was restarted in 2002. The project results could enable an easy identification of outstanding cultivars with desirable traits to be used as gene donors and as resources to rapidly and efficiently select and utilize in rural areas.

The project work is based on two main points:

- Conducting phenotypic characterization of a subset of local sorghum varieties.
- Defining sorghum types and their geographical distribution across the country.

# Material and Methods

## Material

### Preamble

The material used in this research work was constituted by a total of 50 sorghum landraces which I collected from farmer's field during June and July 2006 (Table 2). From the beginning, the aim of the collection was to get an overall view of the existing landraces in Burundi, in addition to the 119 sorghum accessions currently used and conserved at the Sorghum Improvement Program (SIP) at ISABU. This material was to be used for molecular analysis during a training course in ICRISAT-Nairobi during October and December 2007. I was supposed to follow this training course and do molecular analysis of the 169 accessions in the laboratory. But I couldn't go because I had planned to come for this master course in Uppsala which started in September 2007. The sorghum material I collected was used for my master project of morphological analysis during 2008.

### Landraces sampling

The sampling process was conducted throughout the Burundi regions where sorghum is commonly cultivated, from seven out of seventeen provinces in Burundi. Kirundo and Muyinga in North of the country, a region of significant diversity, Bururi and Rutana in the south, Ruyigi and Cankuzo in the East and Cibitoke in the West. Those provinces are characterized by irregular rainfall at such extent that other cereals like maize are not well adapted. The collection sites were selected based on the prevalence of sorghum fields, security and accessibility related to the presence of road and absence of rebels in the surrounding area.

The initial objective of the collection of sorghum landraces was to conserve the sorghum diversity existing under cultivation within ISABU gene bank for future use by the Sorghum Improvement Programme, for which I am responsible. In each sampling location, I visited sorghum fields located along the road and I collected panicles deviating from my previous collected panicles. During the sampling process, the criteria used to choose the landraces was based on the panicle shape and/or grain colour, since these two characters are the most important in sorghum identification. Taking into account the variation within the field, one to three mature panicles were collected. The sampled landrace was designed with a local name as well as the name of locality and a number for identification.

Table 2. Sorghum landraces, collection identities, local names, altitude(m) and administrative zones in which they were found.

| Number | Identity | Local name | Province | Commune | Location | Altitude |
|---|---|---|---|---|---|---|
| 1 | BCBE01 | Amasaka | Cibitoke | Buganda | Nyamitanga | 802 |
| 2 | BCBE02 | Amasaka | Cibitoke | Buganda | Nyamitanga | 802 |
| 3 | BCBE03 | Amasaka | Cibitoke | Buganda | Nyamitanga | 802 |
| 4 | BCBE04 | Amanyarwanda | Cibitoke | Buganda | Nyamitanga | 802 |
| 5 | BCBE05 | Amasaka | Cibitoke | Buganda | Nyamitanga | 802 |
| 6 | BCBE06 | Amasaka | Cibitoke | Buganda | Nyamitanga | 802 |
| 7 | BMCB3 | Amasaka | Bujumbura | Bujumbura | Market | - |
| 8 | BCBE08 | Imponda | Cibitoke | Rugombo | Nyamagana | 897 |
| 9 | BCBE09 | Imponda | Cibitoke | Rugombo | Nyamagana | 897 |
| 10 | BKDE11 | Amasaka | Kirundo | Vumbi | Gasura | 1576 |
| 11 | BKDE12 | Inamurombero | Kirundo | Vumbi | Gasura | 1576 |
| 12 | BKDE13 | Amahwera | Kirundo | Vumbi | Gasura | 1576 |
| 13 | BKDE14 | Rudasakwe | Kirundo | Vumbi | Gasura | 1576 |
| 14 | BKDE15 | Amasaka | Kirundo | Kirundo | Karamagi | 1407 |
| 15 | BKDE16 | Amasaka | Kirundo | Kirundo | Kireka | 1380 |
| 16 | BKDE17 | Amasaka | Kirundo | Kirundo | Kinyangurube | 1380 |
| 17 | BMGE18 | Amashirahamwe | Muyinga | Gasorwe | Butirabura | 1747 |
| 18 | BMGE19 | Amasaka | Muyinga | Gasorwe | Butirabura | 1747 |
| 19 | BMGE20 | Amasaka | Muyinga | Gasorwe | Karira | 1784 |
| 20 | BMGE21 | Amasaka | Muyinga | Muyinga | Mukoni | 1763 |
| 21 | BMGE22 | Amasaka | Muyinga | Muyinga | Mukoni | 1763 |
| 22 | BMGE23 | Amasaka | Muyinga | Muyinga | Rugari | 1616 |
| 23 | BBRE51 | Amahonda | Bururi | Rumonge | Minago | - |
| 24 | BBRE52 | Amahonda | Bururi | Rumonge | Minago | - |
| 25 | BBRE53 | Amahonda | Bururi | Rumonge | Minago | - |
| 26 | BBRE24 | Amahonda | Bururi | Matana | Ntwaro | - |
| 27 | BBRE25 | Amahonda | Bururi | Matana | Ntwaro | - |
| 28 | BBRE50 | Amahonda | Bururi | Matana | Ntwaro | - |
| 29 | BRTE27 | Amahonda | Rutana | Bukemba | Nyaburayi | - |
| 30 | BRTE29 | Amashirahamwe | Rutana | Giharo | Rutambo | - |
| 31 | BRTE31 | Amahonda | Rutana | Bukemba | Kibanga | - |
| 32 | BRTE32 | Amahonda | Rutana | Bukemba | Kibanga | - |
| 33 | BRTE33 | Amahonda | Rutana | Bukemba | Kibanga | - |
| 34 | BRTE34 | Amahonda | Rutana | Bukemba | Kibanga | - |
| 35 | BRYE35 | Amasaka | Ruyigi | Ruyigi | Ruhwago | - |
| 36 | BRYE36 | Amasaka | Ruyigi | Ruyigi | Ruhwago | - |
| 37 | BRYE37 | Amasaka | Ruyigi | Ruyigi | Ruhwago | - |
| 38 | BCZE38 | Ubuheke | Cankuzo | Cankuzo | Kigusu | - |
| 39 | BCZE39 | Ubuheke | Cankuzo | Cankuzo | Kigusu | - |
| 40 | BCZE41 | Ubuheke | Cankuzo | Cankuzo | Kigusu | - |
| 41 | BCZE42 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 42 | BCZE43 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 43 | BCZE44 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 44 | BCZE45 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 45 | BCZE46 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 46 | BCZE47 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 47 | BCZE48 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 48 | BCZE49 | Ubuheke | Cankuzo | Cankuzo | Muterero | - |
| 49 | BMCB4 | Amasaka | Bujumbura | Bujumbura | Market | - |
| 50 | BMCB2 | Amasaka | Bujumbura | Bujumbura | Market | - |

The landrace identification number (Table 2) is composed by four letters where B means Burundi, the two letters CB-KD-MG-RY-CZ-RT-BR-MC show the name of collection province of Cibitoke,Kirundo, Muyinga, Ruyigi, Cankuzo, Rutana, Bururi and Central market. The last letter E is the initial letter of the collector name, here Espérance. The only information I asked and got from the farmers was the local name of the landrace. Unfortunately, the field owners were not always found around to give information about the name of their landraces. In those cases I used the vernacular name common in the region. Each sampled panicles were kept in envelopes with written identification. The sorghum panicles were naturally dried and conserved, waiting for the sowing period, usually held in the middle of December to the middle of January.

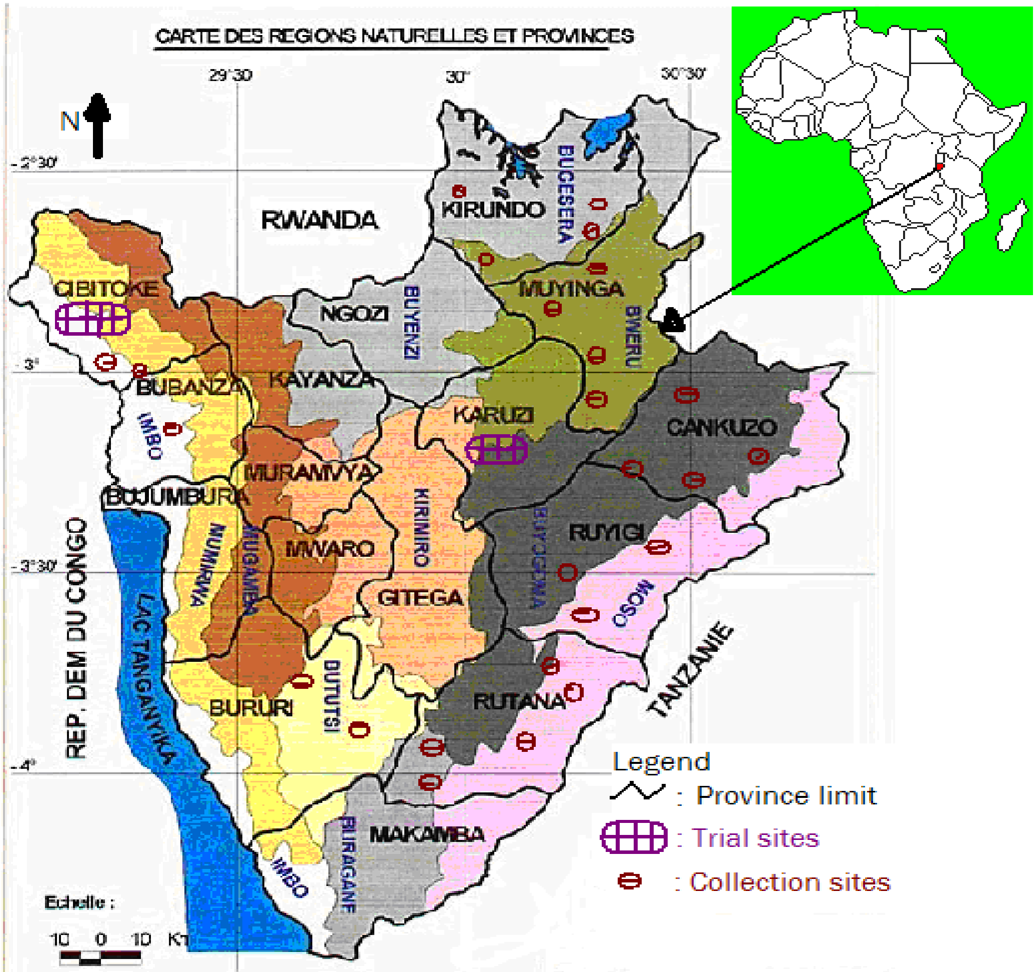
## Methods

### Trial Sites Description

Burundi often called "the heart of Africa" is a small country of 27 834 km$^2$, located in Eastern Central Africa and highly populated (8.6 millions, 2008). Bounded to the North by Rwanda, to the West by Democratic Republic of Congo, and to the East and South by Tanzania, Burundi is a part of the region of great lakes and rift valley. Burundi is known to have a tropical climate in general, but the country is subdivided into eleven ecological zones represented on the map (Fig. 2) that infer differences in agricultural diversity. The evaluation trial was conducted in two locations of Mparambo (Cibitoke province) and Karuzi which belong to the Ministry of Agriculture and Livestock.

Mparambo is located in the Cibitoke province, in Northwest of the country in the Rusizi plain where the climate is typically tropical. The low land province of Cibitoke is longing the Lake Tanganyika at 772 m of altitude above sea level. The type of soil is heavy alluvial soil (black soil) and the soil analysis, in annex to this document revealed 14 ppm of phosphorus, which was within the acceptable levels for cereal production, 0.3 percent of nitrogen and the pH was 6.6. In the low land zone of Burundi the average temperature range between 22 and 25 degree centigrade and the average annual rainfall is approximately 1 000-1 500 mm with big variation due to climate change. The vegetative cycle for sorghum is four months in this location.

Karuzi site is located in the Karuzi province, in the central plateau with a middle altitude of 1550 m above sea level. The location is characterized by rolling hills with low temperatures, compared to the low lands in Burundi. The soil type was poor in mineral elements (ferruginous soil with red colour). Normally this kind of soil is not good for crop production. Inputs in organic matter were quite inexistent. The soil analysis revealed 10 ppm of phosphorus, 0.3 percent of nitrogen and the pH was 4.4 (acidic soil). The temperature range between 15 and 20 degree centigrade. The average annual rainfall is approximately 1 500-2 000 mm in intermediate altitude. The vegetative cycle for sorghum is six months in this location.




Source : ISABU. Modified by MINATE, 2002

Fig. 2: Burundi map showing ecological zones, collection sites and trial sites.

### Field Protocol

The research project was using a subset of 50 sorghum landraces collected in June and July 2006. The dry sorghum seed were sown during the growing season of 2007 in order to multiply and to have enough planting material for further analysis of the landraces at the Sorghum Improvement Program. From the harvest of June 2007, five panicles per landrace were conserved as plant material for sowing the next growing season in January 2008, which was the present master thesis work.

- Experimental design

Three replications per landrace and site were used in order to maintain scientific standards and satisfy statistical analysis requirements. The experimental plot design was a "Complete Randomized Bloc Design". All landraces were planted at both sites using the same randomization. To avoid border effect, each accession was sown into three rows of 5 m length with an inter-row space of 0.75 m and the studied specimens were collected in the middle row. A total area of 0.60 ha with 0.30 ha in each site was used for this master project.

- Cultural practices

The fifty accessions were sown on 17 of January 2008 at Mparambo and on 10 of January 2008 at Karuzi. The seedbed was similar to the one prepared for maize. The sorghum was over planted (sowing density was approximately 6 to 7 kg/ha) in rows at a depth of 10 cm and covered with soil. After two to three weeks when the seedlings had three to four leaves the rows were thinned to about 10 cm between the seedlings.

The nutrient needs of sorghum closely resemble to the needs of maize, except that sorghum demands relatively high levels of nitrogen. Approximately 10 tons/ha of organic matter was applied two weeks before seedbed preparation. The mineral fertilizer NPK was applied in two recommended doses. The first dose of NPK 40-46-30 kg/ha was applied on 22 of February 2008 at Mparambo and applied on 15 of February 2008 at Karuzi. A second fertilizer application of NPK 40-0-0 kg/ha was done before the panicle initiation stage.

Weed control was done manually without chemical application two to three times during the crop duration. Diseases and insects were controlled with chemicals by a special programme of Crop Protection at ISABU according to their protocol and phytosanitary measures in use and recommended by the Ministry of Agriculture and Livestock.

### Morphological characterization

Scoring of phenotypic characters was done on five randomly selected plant specimen in the middle row while the two outer rows were counter for possible border effects. Two categories of data were recorded. Five quantitative characters were measured, based on the metric scale and sixteen qualitative characters were measured, based on an arbitrary scale found in the sorghum descriptors lists from the International Board of Plant Genetic Resources, IBPGR/ICRISAT (1993) as reference for the observations.

- Quantitative characters measured

The plant height was measured in cm at plant physiological maturity. The measurements of five plants randomly selected were taken from the base of the plant to the tip of the head. The weight in g of 1000 seeds was assessed at physiological maturity when the seeds were at approximately 12 percent of moisture content. For the inflorescence length, measurements in cm were made from the base to the tip of the head with the ruler and for inflorescence width measurements in cm were made at the middle of the panicle with the ruler. The number of days to 50 percent flowering was counted from emergence (five to ten days after sowing) until 50 percent of the plants had started flowering.

- Qualitative characters measured

For the stalk juiciness scoring was done at the fourth internode of the stalk at plant maturity stage. The juiciness character was scored as “one” for stalk without juice and “two” for juicy stalk. The juicy stalks were tested for the juice flavour, scoring “sweet” or “insipid”. The leaf mid-rib colour was assessed at plant flowering stage on any of the fully bloomed leaves and divided into 6 classes, based on colour. The waxy bloom, which is a kind of flour found on sorghum leaves and stalk, was assessed at flowering stage into 4 classes. The inflorescence compactness and shape, was assessed into 12 classes according to the descriptors (Fig. A in appendix 3). The inflorescence exsertion, was assessed into 4 classes according to the descriptors (Fig. E in appendix 3). The glume and grain colour were assessed at maturity stage and colour codes found in the sorghum descriptor were used to identify the grain colour (5 classes) and the glume colour (7 classes) (appendix 4). For the grain covering the amount of grain covered by the glumes was estimated into 5 classes at maturity stage as described in Fig. D in appendix 3. The shattering (the way grains are easily or difficultly removed from the panicle) character was scored immediately after physiological maturity into 5 classes. The grain sub-coat was assessed at physiological maturity by scratching the outer seed cover, scoring for absent or present. The grain form was assessed into 2 classes at physiological maturity when the seeds are still in the panicle (Fig. C in appendix 3). The endosperm texture (5 classes, Fig. B in appendix 3), the endosperm colour (2 classes) and the endosperm type (3 classes) were assessed at maturity stage by cutting the seed longitudinally. Magnifying glass was used to see the features clearly. The senescence which is death of plant leaves was assessed at grain maturity into 5 classes. The scores were based on percentages of the senescence observed on the whole plant; excluding the lower three leaves because they normally die before grain maturity. See appendix 4 for an overview of traits and codes used.

### Data analysis

Before analysis of variance, the overall data set was divided into two groups. One group contained quantitative data and the other group qualitative data with coded numbers. For the quantitative data, mean value was used for all characters but for the coded data with variation within one accession a decision was made to use the dominant character and only one code was used per accession. After verification of the data sub set, frequencies of occurrence of each qualitative character were calculated using Excel. The qualitative data was split into two parts corresponding to characters having high variation (more than two groups) within the observed phenotype classes and characters with less variation (one to two groups). General Statistics (GenStat) Discovery, 3rd Edition Program was used for analysis of variance. Descriptive statistics (mean value, coefficient of variation obtained from ANOVA analysis were used to compare the level of agronomic characters variation between locations involved in this study. A least significant difference of $P<0.05$ was accepted as significant (Snedecor & Cochran, 1980). To analyze the similarity between accessions, NTSys-pc 2.1 (Numerical Taxonomy System) was used for hierarchical clustering with UPGMA method (Unweighted Paired Group Method of Arithmetic Averages). Correspondence Analysis (CA) was used with the entire raw data set (qualitative and quantitative data) to get a general view and pattern of variation within the sorghum landraces.

# Results

## Summary comparison of phenotypic classes of qualitative traits with wider variation

This study on morphological characterization revealed a high diversity in sorghum landraces concerning glume colour, inflorescence exsertion, grain coverage, leaf midrib colour, waxy leaves, senescence (death of leaves), shattering and endosperm texture. These characters and their associated percentage are presented in (Table 3).

Table 3. Qualitative traits with wide variability.

| Character | Dominant phenotype and their percentage | | | | |
|---|---|---|---|---|---|
| Glume colour | Black 52% | Red 33% | White 6% | Sienna 4% | Mahogany 5% |
| Inflorescence exsertion | Exserted 36% | Well-exserted 48% | Slightly exserted 17% | | |
| Grain coverage | 25%grain covered 47% | 50%grain covered 35% | 75% grain covered 16% | Grain fully covered 2% | Glumes longer Than grain 0,5% |
| Leaf midrib colour | White 77% | Dull green 19% | Purple 4% | | |
| Waxy bloom | Completely bloomy 1% | Mostly bloom 52% | Medium bloom 38% | Slightly present 9% | |
| Senescence | 20% of dead leaves 46% | 21-40% of dead leaves 30% | 41-60% of dead leaves 19% | 61-80% of dead leaves 3% | |
| Shattering | Very high 5% | High 35% | Intermediate 24% | Low 23% | Very low 13% |
| Endosperm texture | Completely starchy 70% | Mostly starchy 23% | Intermediate 6% | Mostly corneous 1% | |

A majority of the material showed black glumes (51 percent) or red-brown (33 percent). The presence of straw coloured glumes (six percent) and some other intermediate colour like Sienna (four percent) and Mahogany (five percent) were also recorded. The inflorescence exsertion, measured as the amount of exposed peduncle from the flag leaf to the base of the panicle, was recorded to be well exserted with long peduncle. This character (48 percent) found in Guinea sorghum races is the dominant race in Burundi, while poor exsertion is found in Durra sorghum. The groups of exserted and slightly exserted landraces were recorded respectively for 36 percent and 17 percent. The results obtained with regard to grain coverage showed that 82 percent of the landraces had grains which are covered at 25-50 percent by the glumes and some of the landraces had grains which were fully covered (two percent), or covered to ¾ (16 percent) by the glumes. Only one landrace showed longer glumes than the grain. Among the leaf midrib colours observed, white (77 percent) followed by dull green (19 percent) were the most frequent and some accessions showed purple midrib (four percent).

In this collection, waxy bloom on the stalk was recorded as mostly bloomy for 52 percent, medium for 38 percent, slightly present for nine percent and completely bloomy for one percent of the landraces. Sorghum variety with waxy coating character of leaves and stalk is interesting for drought tolerance. Regarding plant senescence, most of the accessions had 20-60 percent of dead leaves after grain maturity. Only three percent of the landraces had dried leaves after harvesting. Those cultivars that remain green are more tolerant concerning drought stress and pest attacks compared to cultivars that dry quickly. Concerning the shattering character all the groups present in the ICRISAT sorghum descriptor was recorded, showing a high variability among the landraces.

The shattering character is an important agronomic character associated to grain coverage and farmers prefer freely threshing landraces and very few accessions had low shattering. The seeds were completely starchy (70 percent) or mostly starchy (23 percent). Six percent of the material had seeds with intermediate texture. During the analysis of endosperm texture, completely corneous endosperm as it appears in the sorghum descriptor wasn't found.

### Panicle shape as a main qualitative character in sorghum identification

In fact the inflorescence shape character is very important in sorghum morphological analysis. From all qualitative traits analyzed during this study, except the grain colour, the panicle shape is easily perceptible by farmers in their fields and it is the main criteria to distinguish their landraces under cultivation. In the present study, the character of sorghum panicle, useful for variety identification and classification, was used as the main criteria during landrace sampling 2006. The morphological analysis revealed eight shape classes and they varied from "compact elliptic panicle" to "very open panicle" indicating a high diversity of sorghum races among the samples (Fig 3).

Many types of panicle shape exist in Burundi sorghum landraces. The highest percentage (22 percent) of the landraces had semi loose drooping primary branches and semi loose erect primary branches (21 percent). Other types of panicle shape (loose drooping primary branches, semi compact elliptic, compact elliptic, loose erect primary branches, half broom, and very loose drooping primary branches) were also present showing a high variation among the landraces. In general, the character of panicle shape is not strongly and directly influenced by the environmental conditions. It is a secondary criterion of sorghum variety identification and can serve as a valuable morphological trait in sorghum diversity studies and a useful trait for conservationists.

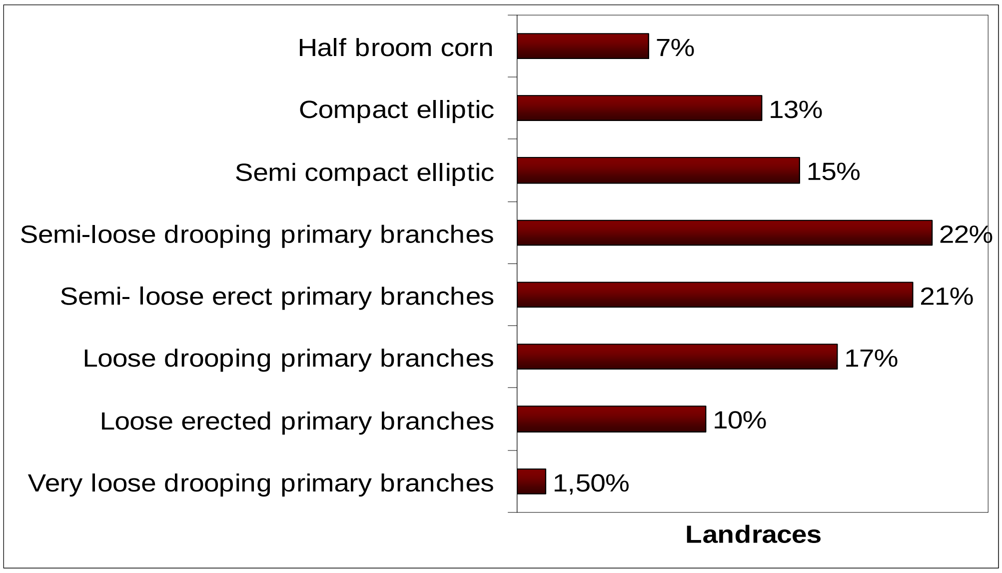



Fig. 3. Inflorescence shapes among Burundi sorghum landraces.

### Grain color as a main qualitative character in sorghum identification

Another important character in sorghum morphological analysis is the grain colour. In this collection, the dominant grain colour of the landraces was red (Fig. 4b) and was observed for 52 percent of the landraces. Brown grains (Fig. 4a) were the second most common colour in this collection and was recorded for 25 percent. Those two colours were recorded in more than 70 percent of the landraces used in this study. The remaining percentage of landraces expressed other colours like orange and yellow colour (Fig. 4c), white colour (Fig. 4d) and some intermediate sub group-colours and these groups were recorded in 23 percent of the accessions.

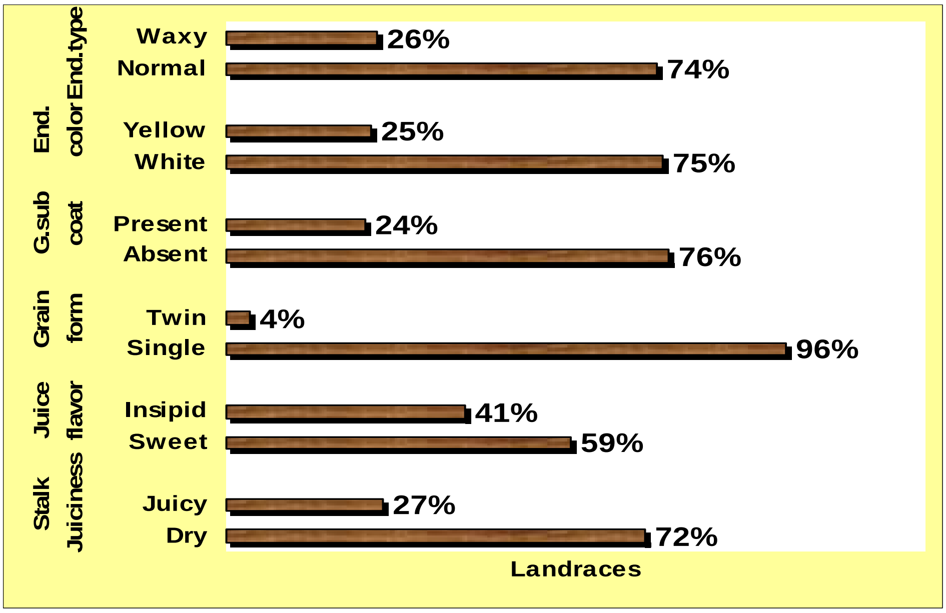
During sampling visits, I noticed that sorghum cultivars with white seeds were more frequent in Kirundo, Rutana and Cankuzo provinces. All those provinces are located on the border of the country. It is likely to be a result of exchange of sorghum material with neighbours from Tanzania. White grain is called "urubere" in the Moso region, located on Tanzanian border and the same name is used by Tanzanian habitants where it might have originated. The colour character was the most complicated character to analyze and a range of variation was noticed between the four main colours (brown, red, white, orange-yellow).

| a. Brown (25%) | b. Red (52%) | c. Orange-Yellow (10%) | d. White (10%) |
|---|---|---|---|

Fig. 4. Diversity of grain colour in Burundi sorghum landraces.
Photo: Espérance H. 2008

## Comparison of phenotypic classes of qualitative traits with less variation

Some of the qualitative characters showed relatively little variation in this sample (Fig. 5). This sub group is composed of the characters: stalk juiciness, juice flavour, grain form, grain sub coat and endosperm colour/type.




Note: G-sub coat= Grain sub coat, End.type/colour = Endosperm type/colour

Fig. 5. Qualitative characters with small variation.

The juiciness and the flavour characters were checked for all landraces at maturity stage in the field. Only 27 percent of the material was juicy whereas 72 percent was dry. Among the juicy sub set of landraces, 59 percent had sweet flavour and 41 percent was insipid. Karuzi site showed a higher percentage of juicy landraces compared to Mparambo site. More than 70 percent of the sorghum material grown in Mparambo location was dry. Twin seeds, one of the rarest characters in this sorghum collection were found only in two accessions (four percent) which mean that the remaining 96 percent of the landraces had single seeds. Most of the grains had no sub coat (76 percent) which is normally associated to the white seeds, with starchy and normal endosperm grain. Yellow endosperm grains were recorded for 25 percent of the landraces while the rest had white endosperm. In fact, among the 21 characters considered in this study, this group of six characters with low variation is constituted by phenotypic characters, usually imperceptible by farmers in their fields. Thus, endosperm type, endosperm colour, sub coat, endosperm texture, are not really interesting for small scale farmers during their selection and choice of sorghum landrace seeds. While characters like panicle shape, grain colour, senescence, shattering and threshing ability are perceptible characters in the field which may influence the farmer's selection.

### Comparison of the two sites using quantitative data

The two trial sites, Mparambo and Karuzi, used in this study were located in two zones of the country with differing altitude, topography, geography and microclimate. During the sorghum growth, some of the characters are probably affected considerably by the different environmental conditions.

In the raw data you can observe differences between the two sites. But to compare the two sites in a more objective way, an analysis was performed using the five characters of plant height (PH), panicle length (PL), panicle width (PW), number of days to 50 percent flowering (D to F) and 1000 grain weight (W1000) (Fig. 6).

The mean values for the five characters in both sites were used to generate the figure. Except for the characters of number of days to 50 percent flowering and the weight of 1000 seeds, the Mparambo site is showing higher mean values of vegetative and yield components of plant height, panicle length and panicle width, than the Karuzi site, where the sorghum plants were short and weak. As for all crops the vegetative vigour is related to the soil where they are growing and the soil of Karuzi was extremely poor and acidic. The vegetative sorghum cycle, from emergency to flowering stage is longer (128 days) in Karuzi compared to Mparambo (67 days) with coefficient of variation of 25 percent. In Karuzi the temperatures were low compare to Mparambo and during night time the temperature drop below 10 degree centigrade and this affect negatively the sorghum growth.  The long time between flowering stage and maturity recorded in Karuzi could explain the fact that the seeds were heavier in Karuzi than in Mparambo site (Table 4).

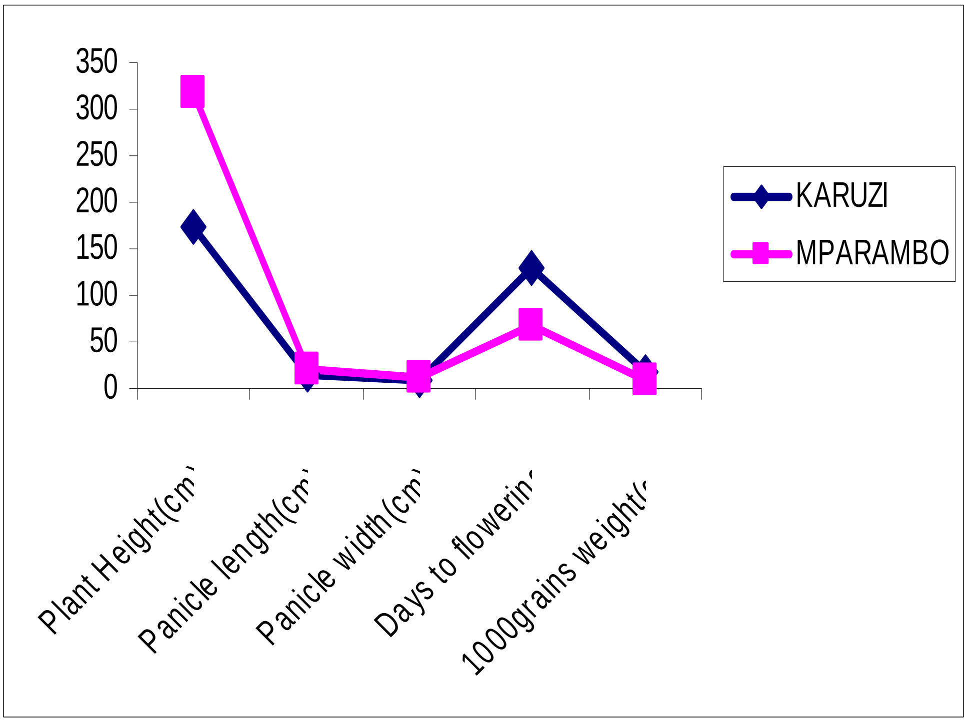



Fig. 6. Comparison of the two sites, Karuzi and Mparambo, using five characters.

Table 4. ANOVA results using quantitative data of five characters.

| | Plant height(cm) | Panicle Length(cm) | Panicle width(cm) | Days to 50% flowering | Weight of 1000 grains (g) |
|---|---|---|---|---|---|
| General mean | 246 | 18.18 | 9.65 | 97.5 | 14.03 |
| Karuzi | 174 | 15.45 | 7.73 | 128.1 | 17.85 |
| Mparambo | 318 | 20.91 | 11.58 | 67 | 10.22 |
| F. prob. | <.001 | <.001 | <.001 | <.001 | <.001 |
| C.V. % | 28.5 | 30.1 | 51.9 | 25.0 | 36.9 |

P<0.05 is significant

The general mean of the five measured characters and the coefficient of variation (C.V.) within the characters are presented. The probability obtained from the ANOVA test in GenStat is presented and can help to detect how much of the differences observed between the two sites are significant according to the five quantitative characters. The ANOVA test indicates significant differences since the probability of Fisher (F. prob) (Snedecor & Cochran, 1980) was less than 0.001 for all characters analyzed. This means that these two sites are showing high significant differences regarding the quantitative characters. The coefficient of variation is observed to be more than 30 percent for the three characters of panicle width, panicle length and 1000 grain weight. The mean value of plant height obtained for Karuzi site is almost half of the mean value of Mparambo.

Comparing the general mean of plant height, panicle length, panicle width and their mean values, Mparambo site showed higher mean value of the characters than the general mean presented; whereas Karuzi site showed smaller mean value than the general mean.

On the contrary, the mean value of days to 50 percent flowering and the weight of 1000 seeds characters were higher in Karuzi compared to the general mean observed. The sorghum seeds mature more slowly in the high land (two months) compared to the low land (one month) and therefore become heavier.

## Clusters analysis

Cluster analysis may help to reveal the relationship between the accessions. Researchers can use it to decide in which plot to place each of the accessions, so that morphological similar accessions can be placed next to each other for variety comparison and for instance, the detection of variety duplications. The clustering may also indicate accessions where molecular markers analysis may be necessary to detect duplicates in collections.

This study is using a large number of sorghum collections and each landrace has been characterized for 21 different descriptors and 16 of them were categorical variables (qualitative) and five of them were numerical variables. In regard of this, the hierarchical dendrograms based on cluster analysis presented in (Fig. 8 & 9) are based on a data set of numerical variables to avoid biased results and estimates due to the combination of continuous and numerical variables. Hierarchical cluster analysis was performed based on a similarity matrix (measures of similarity between each pair of a set of objects) and was done in order to arrange the sorghum landraces into homogeneous groups for diversity analysis.

### Dendrogram of low land site

The hierarchical cluster analysis was performed using the numerical characters of plant height, panicle length, panicle width, number of days to 50 percent flowering and 1 000 seed weight (Fig.7).

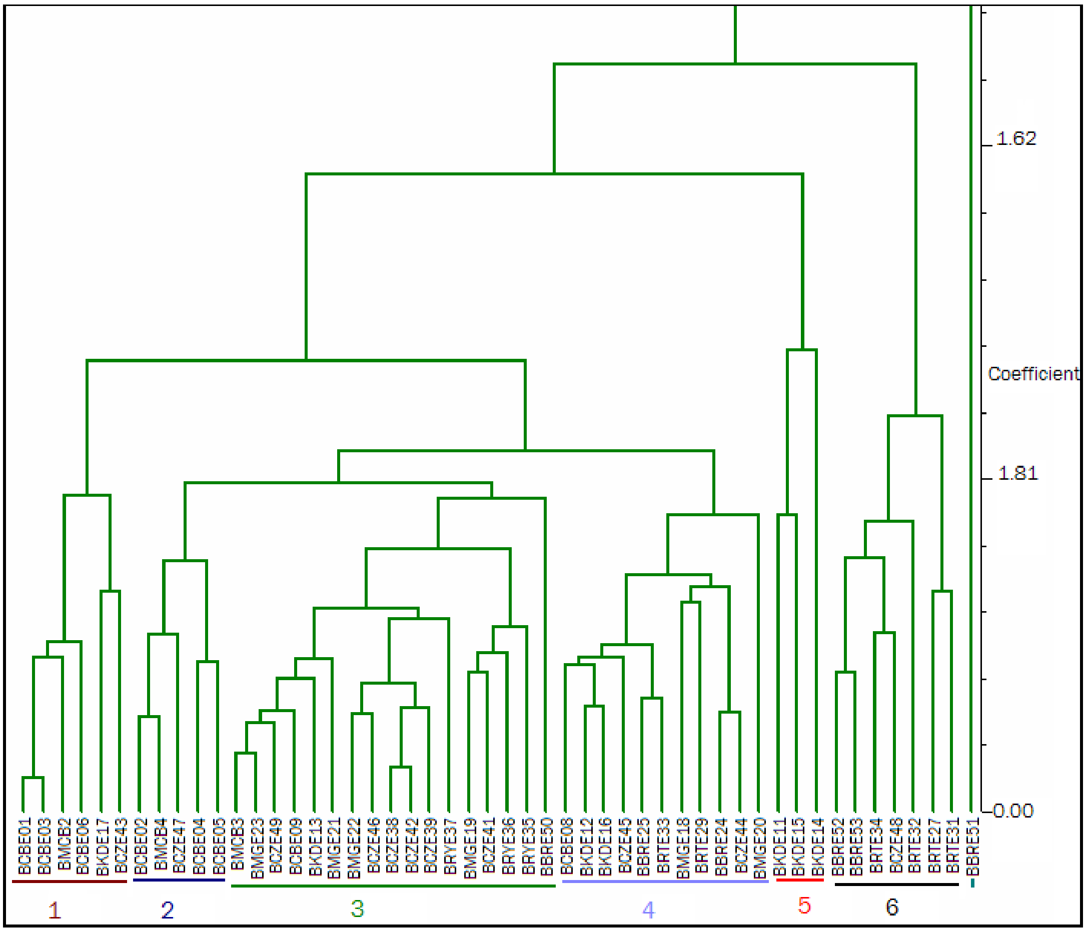



Fig. 7. Dendrogram showing the clustering patterns of sorghum landraces (Mparambo site).

The number of accessions per cluster in (Fig. 7), from Mparambo site, ranged from one to seventeen accessions depending on similar characteristics. The first cluster (1) is composed of six landraces and three of them were collected in the same province of Cibitoke (BCBE01, BCBE03, BCBE06), two others (BCZE43, BKDE17) were collected in Cankuzo and Kirundo provinces and one accession (BMCB2) was collected in Bujumbura market. The second cluster (2) with five landraces show three accessions (BCBE02, BCBE04, BCBE05) collected from Cibitoke and two accessions (BCZE47) and (BMCB04) were collected in Cankuzo province and Bujumbura market. In cluster (3) seventeen landraces were found, mainly collected in the eastern provinces of Ruyigi and Cankuzo. This cluster contains also five landraces originally collected from the northern parts of Burundi that have a climate comparable with the eastern parts. Eleven accessions from six different origins are found in cluster (4) and these regions are differing concerning climate and edaphic conditions. Cluster (5) contains three accessions from the same province of Kirundo (BKDE11, BKDE14 and BKDE15). In cluster (6) there are seven accessions, mainly collected from southern and eastern parts of the country. One accession (BBRE51) is forming its own group, it could not adapt to the low land conditions.

### Dendrogram of middle land site

The same hierarchical cluster analysis was performed for Karuzi site using the same numerical character of plant height, panicle length, panicle width, number of days to 50 percent flowering and 1 000 seed weight. In the dendrogram presented in (Fig. 8), the fifty sorghum landraces were grouped into six different clusters, but the groups clearly differ from those of the Mparambo site.

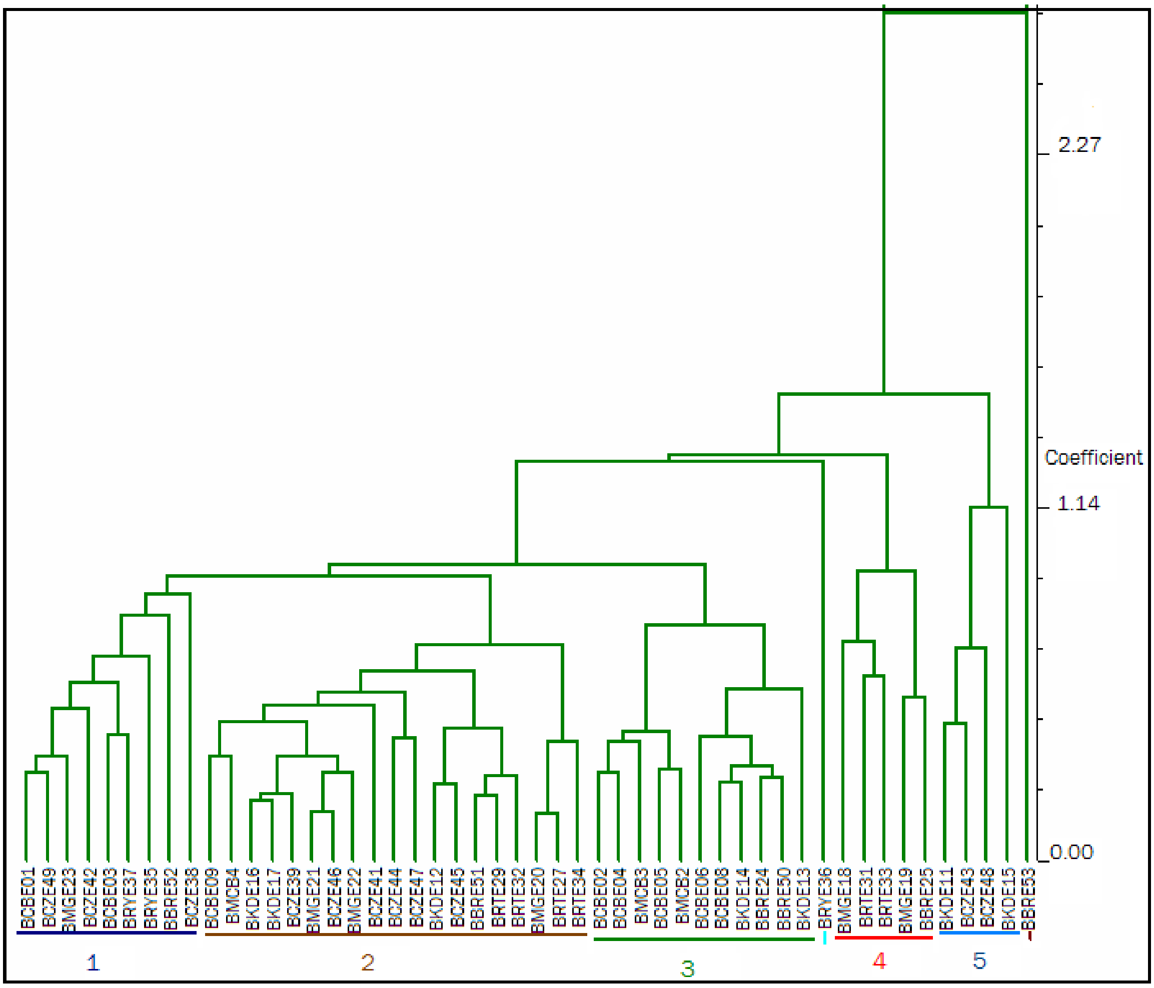



Fig. 8. Dendrogram showing the clustering patterns of sorghum landraces (Karuzi site).

In the dendrogram of the Karuzi site, the number of accessions per cluster was ranged from one to nineteen. The first cluster (1) is composed of nine landraces collected from five different provinces. Three of them were collected from Cankuzo and the others were collected from Cibitoke, Ruyigi, Muyinga and Bururi. In cluster (2), nineteen landraces were found, from seven different locations and three of these locations (Kirundo, Muyinga and Cankuzo) have similar climate. Cluster (3) contains eleven landraces and five of them were collected from Cibitoke province in Northwest of Burundi. There were five accessions in cluster (4) collected from three different provinces of Muyinga (2 accessions), Rutana (2 accessions) and Bururi (1 accession). In cluster (5), four landraces were found, two collected in Kirundo province and two collected in Cankuzo province. Cluster (6) is comprised of one accession from Bururi, which could not adapt to this area.

## Correspondence Analysis

Correspondence analysis also called Correspondence Mapping, or Principal Component Analysis of qualitative data is a statistical visualization method for picturing the association between sites and variables and displaying them along two axes to understand their relationship and how they affect each other. The goal was to get a general pattern and an overview of the entire dataset. This method was chosen because other methods were less effective due to large number of categorical variables (21variables) and objects (50 landraces). The following (Fig. 9 & 10) are supposed to be superposed, but this graph was completely unreadable and therefore the data was separated into two figures.

### Correspondence Analysis of landraces

The data presented were obtained from a computation using all qualitative and quantitative data from the two sites and three replicates used in this study.

The number of variables used during the characterization is too large and the distribution pattern shown by the correspondence analysis revealed a high interference between the different landraces without clear separation. The relationship among the sub groups of sorghum landraces is based on interaction between the 21 variables used in the present study for all regions of collection. However, some landraces were close together according to their geographical origin. The ecological zones where the sorghum material was collected were displayed with some overlapping across the axes and among the landrace groups. Thus one group of landraces collected in one ecological zone (Cankuzo, Ruyigi, Rutana) was subdivided into two sub groups spread over all quadrants. One sub group of landraces collected in Kirundo and Muyinga (10, 12, 13, 18, 20, 21, 22) and another group from the eastern parts of Burundi (35, 36, 37, 38, 39, 40, 41, 42, 43, 46) are closely grouped together, even though these regions are not sharing the same climate and topography. The sorghum landraces originated in the low land zones (1, 2, 3, 4, 5, 6, 8, 9, 23, 24) tend to gather apart of other subgroups and this case concern landraces collected in the western zones of Cibitoke province and Rumonge, longing the Tanganyika Lake.

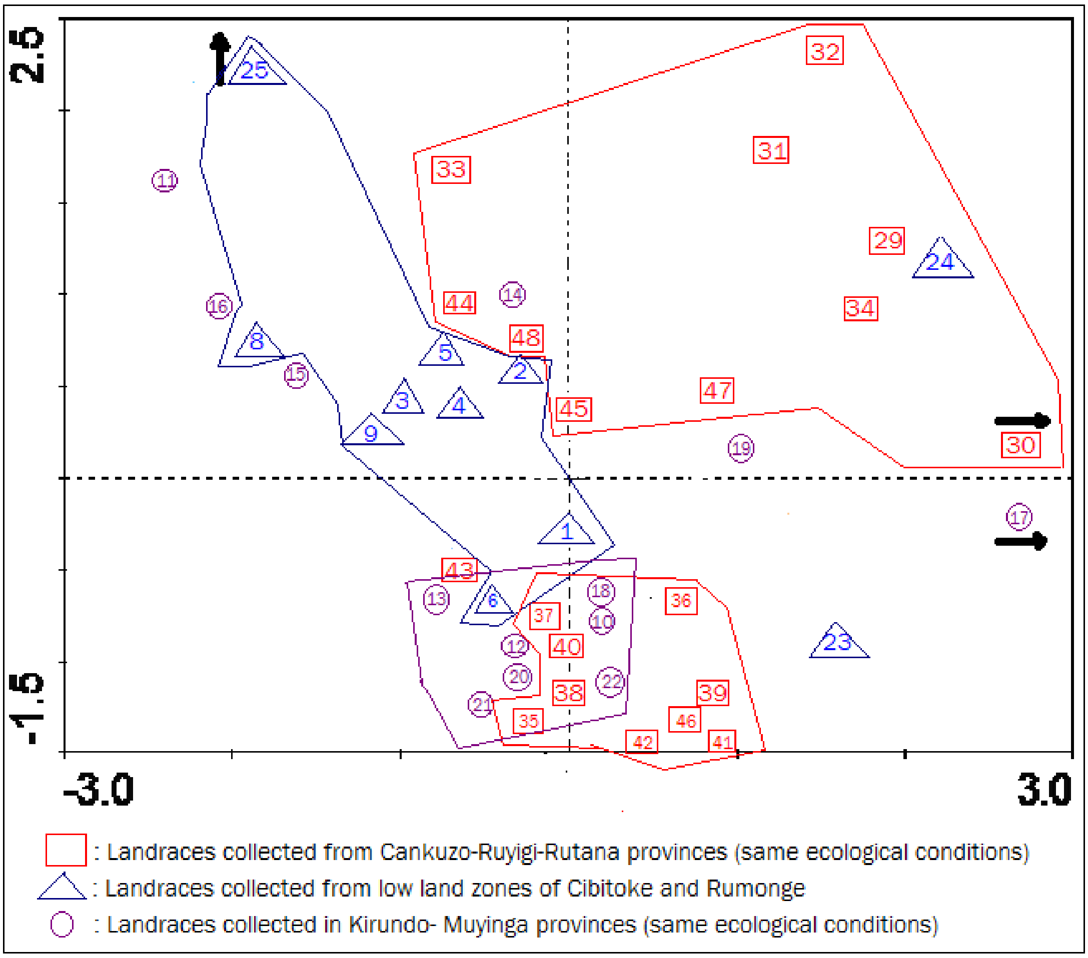



Fig. 9. Correspondence Analysis showing the relationship of the 50 studied Burundi landraces.

Three landraces (25, 30, and 17) were found too far from the centre. Two of these accessions (17, 30) are located in different quadrants and are sharing the rare and interesting character of having twin seeds. Landrace 25, also found outside the main group was collected in southern Burundi and was characterized by a high sensitivity and intolerance to the climate of both of the trial locations.

### Correspondence Analysis of variables

The landraces grouping presented in (Fig. 9) is affected by variables located in the same quadrant of the axis and the variables behind this effect are presented in (Fig. 10). The figure is explaining the general pattern of Burundi landraces displayed in the previous figure (Fig. 9) regarding distribution of landrace's groups and their geographical distribution or concerning landraces out of different sub groups.

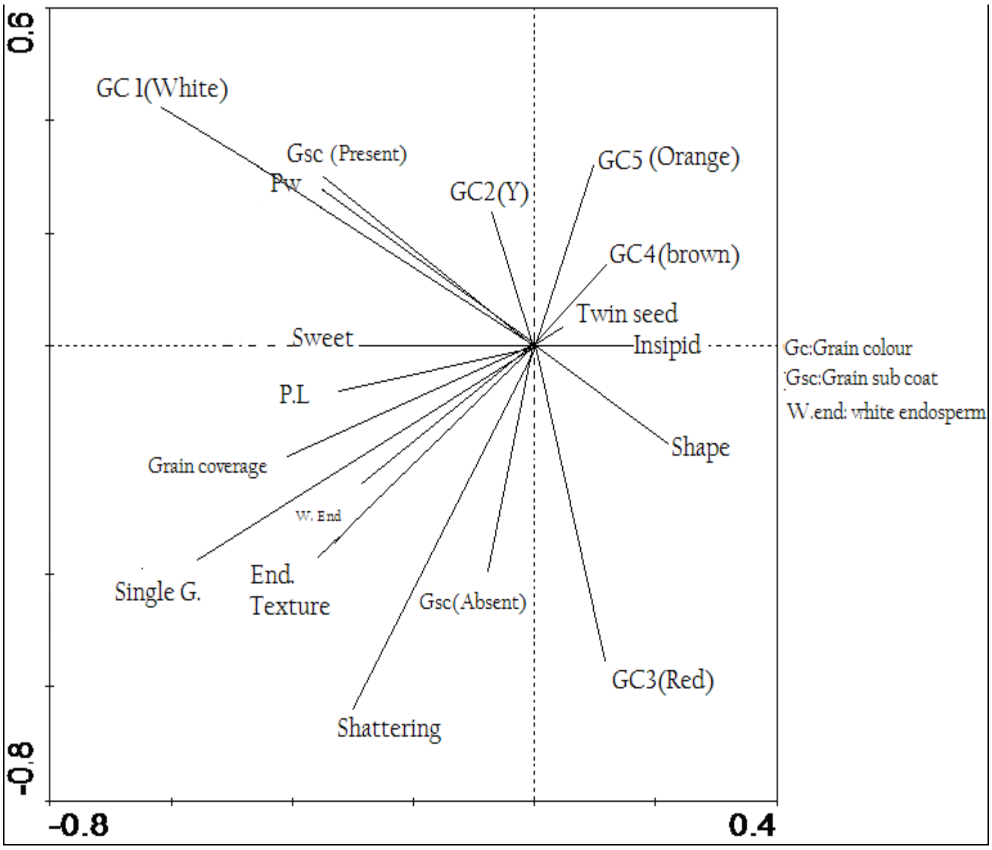



Fig. 10. Correspondence Analysis showing the interrelationship of the more important variables affecting the relationship of the 50 studied Burundi landraces.

The arrows with corresponding variables in each axis quadrant is contributing significantly to gather together different landraces either in a positive or negative way in distinct direction on both sides of the axes. For small sample analysis, those two figures are shown together to get an overall information about how the landraces are influenced by these traits. However in this case (50 landraces and 21variables), the graph became overcrowded and difficult to interpret.

There were two "twin seed" landraces (17, 30) which have been collected in Muyinga and Rutana. These accessions are located in same direction as the variable of twin seed. White sorghum landraces were observed to be found mainly in Rutana, Kirundo and Cankuzo province; and the diagram show that they are located in the same direction as the "white seed" variable. A range of variability in seed colour was observed and five arrows are found in three quadrants. In the variable diagram, we notice that there is a correlation between some variables like white seed and the presence of sub coat in this study as mentioned earlier.

The longer arrows have more influence on the landraces appearing in the figure. The very short arrows representing a minor influence on the landrace distribution were taken away. Some character like white grain colour (GC1), shattering, single grain, red grain colour (GC3) and endosperm texture were the most important for the landraces distribution.

# Discussion

The morphological characterization analysis of Burundi sorghum landraces showed a high occurrence of red and brown grain colour. The predominance of red and brown sorghum seed may be explained by the fact that sorghum is mainly grown for brewing traditional beer, where red and brown grains with high content in tannins are preferable to make a coloured beer with good flavour, while white sorghum grains, which were very few in this sample, are grown for porridge. Variable social habits concerning the use of sorghum may lead to variation in abundance and occurrence of landraces (Adeline et al., 2007). Since Burundian farmers grow different varieties in the same field; the high variation observed in grain colour, with intermediate colours, could be the result of sorghum out crossing and natural selection. In absence of bird damage and/or grain mould, good food quality is usually associated with white seeds (Doggett, 1982). In this study, white seed cultivars were mainly found in Kirundo, Rutana and Cankuzo provinces located on the borders to Tanzania and Rwanda, where farmer's habit and use could differ from other parts of Burundi. Traditionally, there was an extensive exchange of sorghum seeds of different landraces from farmer to farmer and this mechanism might have affected the actual crop distribution and use habit. Burundian farmers are still exchanging sorghum seeds according to their needs and choice.

In the studied material there was a total absence of completely corneous endosperm texture, which is preferred when making "ugali" (thick African porridge) and for long storage period of the grain (Ayana, 1998). This absence of corneous endosperm may be a result of human selection due to the use of sorghum grain mainly for beer. The absence of sub coat in most of the accessions may be explained by the fact that most of the landraces were red and brown and sub coat is usually associated to white sorghum. On the other hand, the low occurrence of grain with sub coat, which make grains hard and difficult to grind, may be related to human selection to avoid hard grains since grain grinding was done manually, using two stones. Traditionally, the process of seed milling for beer was done by women only, and they were mainly involved in seed conservation for their households.

The occurrence of semi compact, loose and open panicle types in the sorghum collection confirmed the existence of Caudatum, Guinea and Bicolor races and their combinations in Burundi. Concerning classification of the landraces, the most common races were Guinea-Caudatum race (often with open panicle), Bicolor-Caudatum race (loose panicle), Caudatum- durra race (often with moderately compact panicle). Pure durra race was absent in this study sample (characteristic of compact oval panicle) (Adugna et al., 2002). The presence of intermediate races of Guinea, Caudatum and Bicolor is reflecting and confirming the idea from ICRISAT researchers that Guinea is basically a West African race with a secondary centre in East Africa, primarily in Malawi, a country not far from Burundi. Caudatum race is dominant in most parts of Uganda, and it might have spread into Burundi region and been crossed with Bicolor, a strictly east African race (ICRISAT, 2008). The affinities and distribution of Guinea indicate that the race was probably derived from selection among wild members of the variety Arundinaceum, with tall plants and open panicles, found across Congo and Burundi region.

In the present study, most of the landraces were observed to be dry at maturity stage. This character of juiciness or pithiness may be related to environmental conditions during the crop season. The two sites were too dry for some of the sorghum landraces collected from humid areas of the country. Juicy cultivars are likely to be interesting and hold a potential with regard to ethanol production, but to maximize plant production, juiciness should be associated to high biomass production (Belum, 2007). Sweet stalked cultivars with high yields of dry matter are also interesting as forage for livestock feed or used for cowshed roofs. In fact, according to the utilization, sorghum disposes interesting panicle characters for those who are using sorghum grains as human food. For human consumption, sorghum with white seed is recognized to make good porridge while red and brown are preferable for good traditional beverage. Sorghum has also important vegetative characters which are preferable for feeding animals, such as cultivars with high fresh or dry biomass. Non senescent cultivars are also preferable since they can remain for a long time in the field during the dry period for grazing.

The considerable differences noticed comparing the results of the two sites (Fig.6 &Table 4), with regard to plant height may be related to the high temperature during the rainy season in the low land of Mparambo. There was a high variation in panicle length and width between the sites. These agronomic components contribute significantly to grain yield and are associated to the vegetative vigour and growth of the plant. The differences between the two locations made the landraces to exhibit a wide range of plant morphological characters and crop duration and the same varieties grown in the two distinct environmental conditions of Mparambo and Karuzi reacted differently. There is a big difference between the sites concerning the vegetative cycle and the inflorescence size for the same variety. Like all plants, the physiology change according to the environmental conditions and all the phenotypic variation in different characters expressed in this material, show that the sites of Mparambo and Karuzi have rather different environmental conditions. According to the basal requirements for plant growth (nutrients in the soil, water, temperature, light, humidity, oxygen etc.), there was a lot of changes in the plant morphology, induced or caused by the plant physiology, to meet the environmental conditions where the plant was growing. Thus the plant has expressed those changes in different ways and this is a good indicator that selection, based on plasticity is feasible and possible in sorghum (Schichtling, 1986)

The results show that a difference in temperature and altitude induced a big difference in flowering time and plant maturity. The observed proportion of plant height may be related to the nature of the soil, since the Karuzi site had an acid soil (pH=4.4) while Mparambo had nearly neutral soil (pH= 6.6). The effects of lower levels of mineral elements in the Karuzi soil contributed to the fact that the plants were less developed. Since the magnesium content in the Karuzi site was low, this might have affected the uptake of nitrogen, which was within acceptable levels in both sites as it was revealed by the soil analysis presented in appendix one. Vegetative characters and inflorescence size are strongly associated with the soil type, altitude and local climate conditions for all crops in general, while qualitative characters are not really influenced by the agro ecological conditions.

Agro morphological characters are highly variable within the landraces; only six qualitative characters didn't show so much variation. Although quantitative characters are influenced by the environmental conditions, they should not be excluded or neglected by conservationists in different processes of crop diversity studies (Yao, 2007). They are still important and essential for farmers whose crop selection is based on phenotypic characters. Some qualitative characters such as panicle shape and grain colour are not directly influenced by the environmental conditions. But these characters are perceptible by farmers in the field, and are valuable criteria in sorghum diversity analysis, while characters like endosperm structure and grain sub coat concern the sorghum scientist more than small scale farmers.

With hierarchical clustering analyses, a considerable variability was observed between and within the clusters. In spite of that the landraces have been collected in different provinces of Burundi, some accessions are similar and are sharing cluster and some landraces originally collected in the same province are placed in different clusters. Thus even though they have been originally collected in different regions, the landraces are sharing some morphological characteristics. The two dendrograms obtained by using separated sites, grouped the accessions rather differently. This confirms that the expressed morphological characters were relatively different in those two environments.

Some of the variation among the landraces may be due to the collection technique in 2006. Data about the history of each seed samples could not be collected. There had been a long time with war or unstable political conditions which negatively affected the agricultural production possibilities. When the political situation stabilized and the agricultural production could start again,

some farmers perhaps had sorghum seeds from local varieties, while other farmers had to get new seeds from other geographical regions. Therefore landraces from different geographical and ecological regions could be grown in the same area. But it is hard to determine the importance of this factor.
In cluster (1) of Karuzi dendrogram (Fig. 8), the nine sorghum accessions are sharing some important characteristics for sorghum cultivation. They are all short in height (< 2m) and characterized by short vegetative cycle to maturity. In clusters (2, 3 & 4) the accessions were mainly gathered together according to the climatic zones and most likely the same growing conditions. Since the hierarchical cluster analysis operates based on a similarity matrix, the landraces were gathered together into homogeneous groups which could be a useful tool for researchers to make a quick identification of cultivars to be used in a sorghum improvement programme. The dendrogram will show approximately the distances between cultivars based on their measured morphological traits.

In this study of sorghum diversity, the political subdivision of Burundi was used during material collection, without any consideration of ecological conditions. Variation in agro ecological regions could partially explain the distribution variation observed between and within the clusters. Some landraces could not adapt to the environment in which they were grown in this study. Moved from hot to cold regions those accessions had incomplete flowering which stopped during the inductive process. One accession was not able to reach the flowering phase as shown below (Fig. 11).


Fig. 11. Sorghum in flowering phase, with one accession not being able to flower. Photo: Diallo, 2008

In the high land, the sorghum cultivars which don't reach the flowering stage could be recommended to be used as animal fodder where this trait could be more useful. The variety presented in the photo above is widely cultivated in the low land of Cibitoke where it is used in banana beer fermentation. More research on the cultivar is needed for clarification and understanding.

# Conclusions and Recommendations

To understand the morphological diversity correlated to the landraces distribution in a country is an important tool for efficient exploitation of crop genetic resources. This characterization study using 21 characters showed a wide range of variation recorded in both quantitative and qualitative characters and for some characters a variation was found also within accessions. The 50 studied landraces revealed an impressive range in morphological diversity existing among Burundian sorghum landraces. The farmers in some areas are still maintaining sorghum diversity. This study has come up with recognition and identification of a high potential diversity with both desirable and undesirable traits which can be used to improve sorghum production for many purposes. The results observed, may help sorghum researchers in the choice of site and sorghum varieties during crop selection experiments and trials in the farmers' fields. The information generated by this master thesis will facilitate the conservation and utilization of the material.

Quantitative characters alone should not be used for sorghum diversity analysis, since they are closely related to the ecological conditions where the crop is grown. Plant morphological analysis should be done under the environmental conditions where they have been collected to minimize the risk of misconception of the morphological traits due to new environmental conditions. In this investigation, sorghum expressed plasticity for a number of morphological characters regarding organ size. Therefore, phenotypic diversity analysis should be associated to genetic analysis for better conclusions. The variability observed among the sorghum landraces, a crop highly neglected in Burundi, showed urgent necessity to develop new strategies for in situ conservation.

The relationship between phenotypic diversity and geographical origin were not significant according to the cluster and correspondence analyses. Even though the landraces were collected in the same or different geographical zone, they still maybe the same cultivars since Burundi is a small country where crop material is easily exchangeable.

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# Appendix 1. Results of soil analyses in the trials sites of Mparambo and Karuzi

| Site | pHw | CE | C | N | P | $A_T$ | $A_{AL}$ | $A_H$ | K | Na | Ca | Mg | CEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mparambo | 6.64 | 119.3 | 2.07 | 0.26 | 14 | 0.07 | 0 | 0.07 | 0.94 | 0.06 | 16.88 | 8.43 | 25.2 |
| Karuzi | 4.43 | 152.6 | 1.91 | 0.34 | 10 | 1.86 | 1.31 | 0.55 | 0.20 | 0 | 0.70 | 0.55 | 9.2 |

pHw : pH water

CE : Electric conductivity (µS/cm)

C : total carbon (%)

N : Total nitrogen (%)

P: phosphorus (%)

AT: acidity (milliequivalent/100g of soil)

AAL: alumunic acidity (milliequivalent/100g of soil)

AH : acidity caused by hydrogen (milliequivalent/100g of soil)

K : Potassium exchangeable (milliequivalent/100g of soil)

Na : sodium exchangeable (milli equivalent/100g of soil)

Ca : calcium exchangeable (milli equivalent/100g of soil)

Mg : magnesium exchangeable (milliequivalent/100g of soil)

CEC : capacity of cathion exchangeable (milliequivalent/100g of soil)

Ca/Mg acceptable level: 3 - 5

Mg/K acceptable level: 2 – 5

(Ca+Mg)/K acceptable range 12 - 30

Mparambo soil : Ca/Mg = 2.0

Mg/K= 8.97

Ca+Mg)/K=26.

Karuzi soil : Ca/Mg = 1.3

Mg/K= 2.75

(Ca+Mg)/K=6.25

# Appendix 2. Soils samples from the Karuzi and Mparambo sites

| | |
|---|---|
|  |  |
| Karuzi soil | Mparambo soil |

# Appendix 3. Pictures of different characters used in the morphological characterization (Sorghum descriptor IBPGR/ICRISAT, 1993)

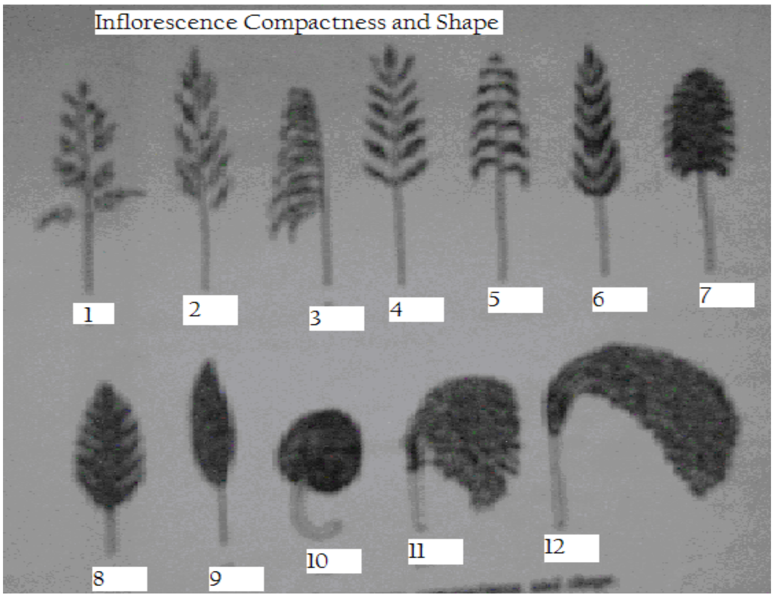


Fig. A) Inflorescence compactness and shape: 1: very lax panicle 2: very loose erect primary branches 3: very loose drooping primary branches 4: loose erect primary branches 5: loose drooping primary branches 6: semi-loose erect primary branches 7: semi-loose drooping primary branches 8: semi compact elliptic 9: compact elliptic 10: compact oval 11: half broom corn 12: Broom corn

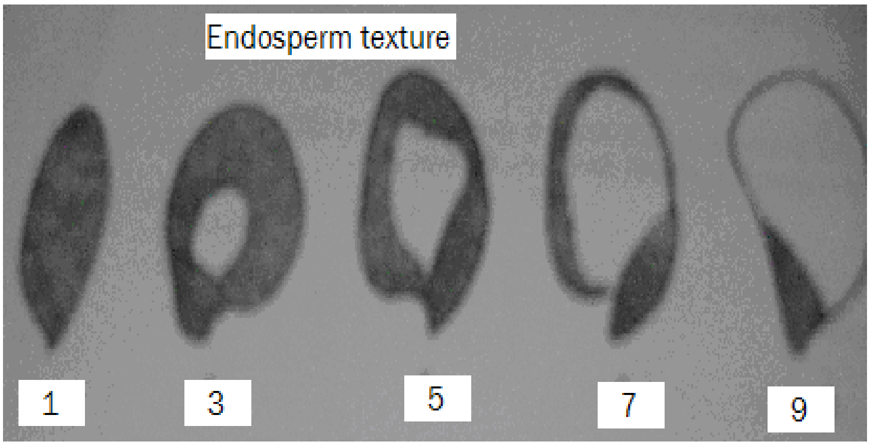


Fig. B) Endosperm texture: 1: completely corneous; 3: mostly corneous; 5: intermediate; 7: mostly starchy; 9: completely starchy

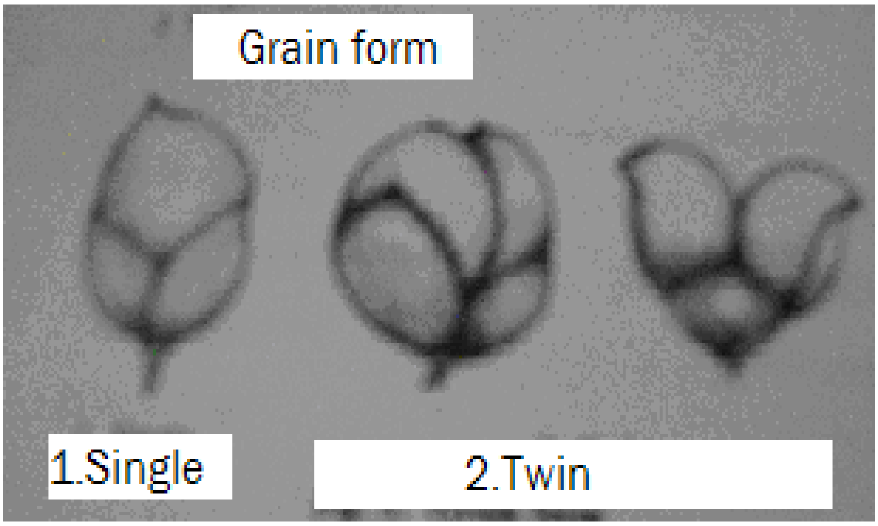


Fig C) Grain Form

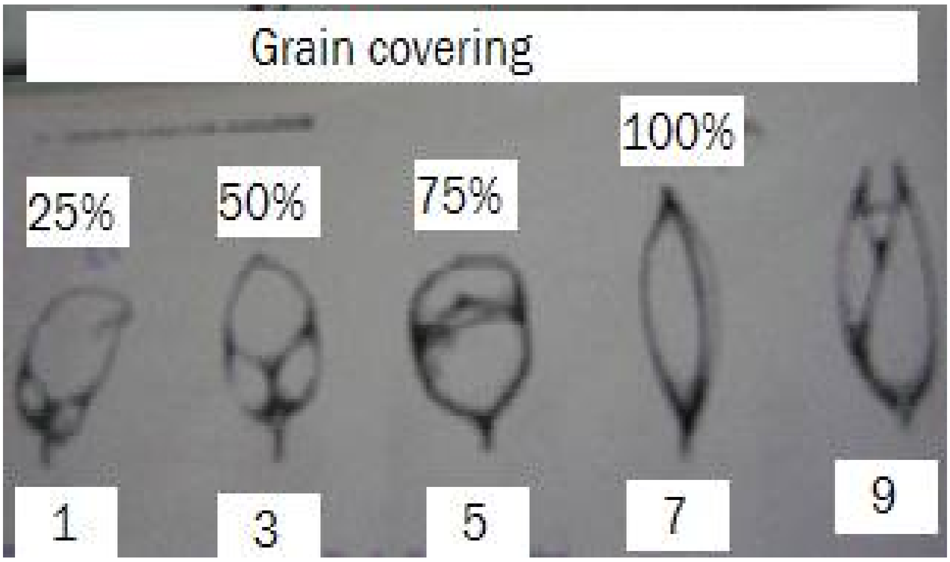


Fig. D) Grain covering

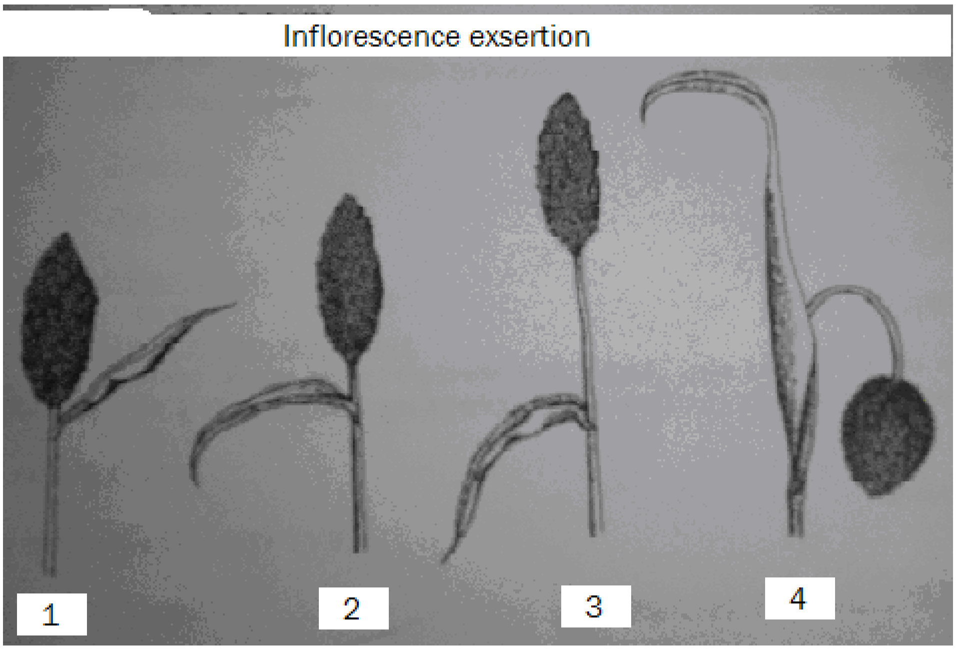


Fig E) Inflorescence exsertion: 1: slightly exserted 2: exserted 3: well exserted 4: peduncle recovered

# Appendix 4: Character, descriptions and their associated codes used in the study

| Traits | Variables and associated codes |
|---|---|
| **Quantitative traits** | |
| 1.Plant height | Measurements taken |
| 2. Panicle length | Measurements taken |
| 3. Panicle width | Measurements taken |
| 4. Weight of 1000 grains | Grains weighted in grams |
| 5. Days to 50% flowering | Counted from the emergence to 50% plant flowering |
| **Qualitative traits** | |
| 6. Stalk juiciness | 1: dry; 2: juicy |
| 7. Juice flavour | 1: sweet; 2: insipid flavor |
| 8. Leaf mid-rib colour | 1: white ; 2: dull green;<br>3: yellow; 4: brown; 5:purple |
| 9. Waxy bloom | 3: sightly present; 5: medium;<br>7: mostly bloomy; 9: completely bloom |
| 10. Inflorescence exsertion | 1: slightly exserted, 2: exserted<br>3: well exserted 4: peduncle recovered |
| 11.Panicle shape | 1: very lax panicle<br>2: very loose erect primary branches<br>3: very loose drooping primary branches<br>4: loose erect primary branches<br>5: loose drooping primary branches<br>6: semi-loose erect primary branches<br>7: semi-loose drooping primary branches<br>8: semi compact elliptic,<br>9: compact elliptic,<br>10: compact oval,<br>11: half broom corn,<br>12: Broom corn |
| 12. Glume colour | 1: white; 2: sienna; 3: mahogany; 4: red; 5: purple; 6: black; 7: grey |
| 13. Grain covering | 1: 25% grain covered; 2: 50% grain covered;<br>3: 75% grain covered; 4: grain fully covered;<br>5: glumes longer than grain |
| 14. Grain colour | 1: White; 2: Yellow;<br>3: Red, 4: Brown; 5: Buff |
| 15. Shattering | 1: very low 3: low 5: intermediate 7: high 9: very high |
| 16. Grain sub-coat | 1: absent, 2: present |
| 17. Grain form | 1: single, 2: twin grain |
| 18. Endosperm texture | 1: completely corneous; 3: mostly corneous;<br>5: intermediate; 7: mostly starchy;<br>9: completely starchy |
| 19. Endosperm type | 1: normal, 2: waxy, 3: sugary |
| 20. Endosperm colour | 1: white , 2: yellow |
| 21. Senescence | 1= 20% senescence; 2= 21-40% senescence;<br>3= 41-60% senescence; 4= 61-80% senescence;<br>5= 81-100% senescence |