Suggestion regulating for post-harvest operations: new trends in maize storage techniques in Rwanda

Made by: HABIMANA Innocent

Supervisor: Ing. Ludmila Skarkova CSc.

A Research Report Submitted to the Czech University of Life Sciences Prague, Faculty of Engineering in fulfillment of the requirements of the degree of Master of Technology and Environmental Engineering

Prague

2014

Declaration

This research report is my own unaided original work, unless specified to the contrary in the text. It is submitted in partial fulfilment of the requirements for the degree of Master of Technology and Environmental Engineering at the Czech University of Life Sciences, Prague. It has not been submitted before for any other degree or examination at any other university.

....

Innocent HABIMANA

Date:

Prague

Dedication

To Christine Uwamahoro, my beloved wife

To Sabine Peace Irasubiza, my daughter

To Yvan Hope Iranzi, my son

To NTAMWEMEZI Francois, my father

To UWABIKIRA Marie, my mother

To my brothers, sisters and friends

Acknowledgements

First and foremost, I would like to thank God for the good healthy given to me to reach this far.

I am extremely grateful to Ing. Ludmila Skarkova CSc., who whole heartedly accepted me to be my Supervisor. From the bottom of my heart, many and many thanks for her support and guidance, without which I would not have been able to complete this study.

I thank the officials of the Rwanda National Strategic Grain Reserve (NSGR) for giving me access to their Institution. They provided me with full access to all institution's grain storage Infrastructure and Institution documents pertaining to the study without any restrictions. They also made sure I had all the information I needed for this thesis. I also thank Mr. Jules Ceaser HALORIMANA for taking me round the Institution and explaining each process to me.

I also say big thank you to Dr. Vladimir Erban of food Research Institute for helping me with the water activity of my maize grain samples.

I thank Ing. Vladimir Plachy, Phd for helping me with the determination of fat content of the maize grain samples.

I am thankful to the government of Czech Republic for funding my studies through the " Czech Government scholarship for developing countries" Also, in the same regards, I am thankful to the Ministry of Trade and Industry of Rwanda (MINICOM) officials for the financial support they kept disbursing to my family.

Last, but not least, my thanks go to my family in general, and to my beloved wife Christine UWAMAHORO in particular, for enduring my absence from home during the course of my studies in Czech Republic. Also, to Sabine Peace Irasubiza my daughter and Yvan Hope Iranzi, my son who sacrificed their joy of being together with their father, to let me finish the course.

Abstract

Maize is the dominant staple food in many parts of Africa. A wide variety of maize types, particularly in Eastern and Southern Africa are produced. New trends in maize storage technology are also coming with added challenges. Maize is stored at various stages of commerce right from production, distribution and as it is being utilized and consumed. The unfavorable climatic conditions of Africa do pose a challenge to the storage of this important staple food during distribution. Being a staple food, maize consumption in Africa is very important as it contributes significantly to caloric and protein intake. The importance of maize is also amplified by the home and industrial food applications in Africa.
Despite maize being a staple food for many parts of Africa and especially in Rwanda for which this research was done; literature is either scarce or non-existent on the stability of functional properties of maize during storage. Therefore, this research undertook to contribute to filling-up this gap. The research work undertook to study the Suggestion regulating for post-harvest operations, and especially for the new trends in maize storage techniques in Rwanda.

The researcher is therefore interested in how best the maize storage techniques in Rwanda can be maximized. Taking .into consideration the local way of maize storage, the modern technology of maize storage and how to improve on it.
He therefore looked at postharvest operations in the same time suggesting rugulation measures to be taken.
For the material, methods , results and discussion, maize samples produced localy have been analysed , and the local techniques of maize storage in Rwanda were compared to the modern technology of Grain storage in the Controled CO_2 Atmosphere, which techniques is perfomed in Czech Republic.

Finally the conclusion and recommendations are made.

Key words: Maize storage techniques, Maize grain, postharvest operations, Rwanda

Contents

List of tables

List of figures

1. INTRODUCTION

1.1 Importance of maize

Maize is the most important cereal grain in the world, providing nutrients for humans and animals and serving as a basic raw material for the production of alcoholic beverages ,starch, oil and protein, , food sweeteners and fuel. After harvest of the grain, the dried leaves and upper part, including the flowers, are still used today to provide relatively good forage for ruminant animals owned by many small farmers in developing countries. The stalks, which in some varieties are strong, have been used as long-lasting fences and walls. (CIMMYT and IITA, 2010).

Figure 1. The Rwanda National Strategic Grain Reserve

Source: Habimana (2013)

In Africa, maize is primarily grown by small-scale farmers for use as both human food and animal feed. Its cob is consumed in different ways. For example, it could be grilled, boiled, roasted or made into various products (Pingali & Pandey, 2000).Industrially, maize is used to produce alcohol, starch, pulp abrasive, oil in the pharmaceutics and recently for fuel production (Morris, 2007; Acharya & Young, 2008; Tom, 2008). In Zimbabwe, maize is used for other non-food purposes such as beer brewing and in exchange for goods and services (Stanning, 1989). The principal producers of maize in sub-Saharan Africa are Kenya , South Africa and Tanzania, followed by Ethiopia and Nigeria (Kfir, 1998; Polaszek and Khan, 1998; Seshu Reddy, 1998). Increased productivity in staple food, such as maize, is critical to raising rural incomes and stimulating broad-based economic growth (Eicher&Byerlee 1997). The demand for maize in developing countries, arguably, surpasses the demand for both wheat and rice. This is as a result of the growth in meat and poultry consumption, which has rapid increased the demand for maize as livestock feed. Thus, the exploding demand for maize presents an urgent challenge for most developing countries(Polaszek & Khan, 1998).

1.2 World and local production of maize

Maize (*Zea mays L.)* is an essential component of global food security. Maize is one of the most important cereal crops grown in the world and it forms one of the major diets of millions of people.

In many parts of Africa maize has become the Preferred cereal for food, feed and industrial use, displacing traditional cereals such as sorghum and millets. Maize production in Sub-Saharan Africa tripled from the early 1960s to late1990s because of nearly 2-fold in- crease in area under cultivation and a > 40% increase in productivity.

The greatest gain occurred in West Africa (350% for production, 64% for productivity and 170% for area), particularly in Nigeria where the increases were 385% for production, 46% for productivity and 231 % for area (FAa STAT, 2003). Consequently, maize consumption is high in Africa, ranging from 85 kg/year per person in Eastern and Southern Africa to 105kg/year per person in West Africa (FAa,2005)

Table 1. World production of maize

World and regional production of maize, (representation for five years average 2004–2008)

	Production (million metric tonnes)	**Percentage (%)**
Wolrd	**752.05**	**100**
Africa	49.57	6.59
Asia	209.61	27.87
Australia and New Zeland	0.56	0.07
Central America	25.28	3.36
Europe	84.01	11.17
North America	307.54	40.89
South America	74.86	9.96

Source: www.faostat.fao.org (2010)

Table 2. Africa Production of maize, (representation for five years average 2004–2008)

	Production (million metric tons)	**Percentage (%)**
Africa	**49.57**	**100**
North Africa	5.05	10.19
Eastern Africa	8.98	18.12
Central Africa	9.79	19.75
Southrn Africa	14.63	29.51
Western Africa	11.11	22.41

Source: www.faostat.fao.org (2010)

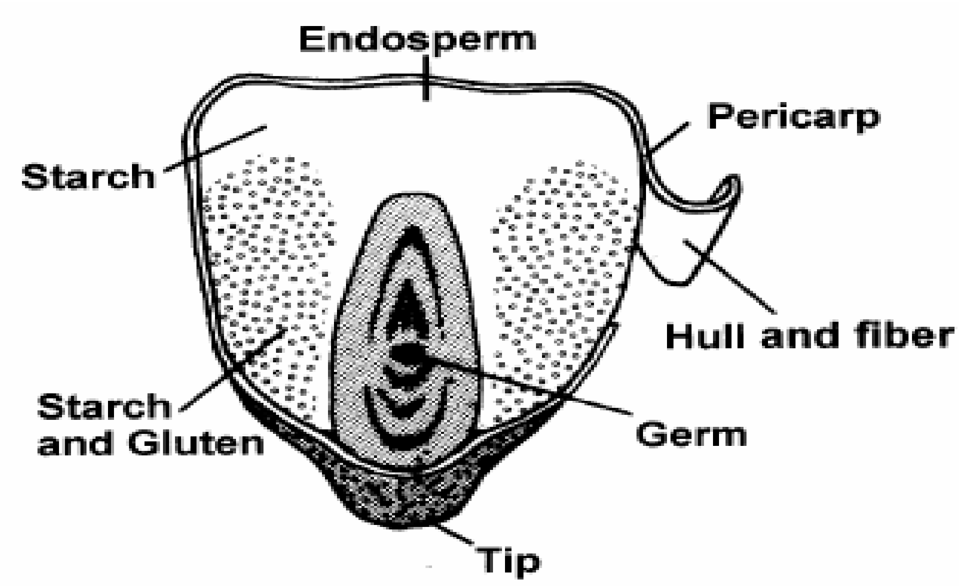
2 LITERATURE REVIEW

2.1 Botanical description of maize

Botanically, maize (*Zea mays*) belongs to the grass family (*Gramineae*) and is a tall annual plant with an extensive fibrous root system. The plant is a cross pollinating species, with the female (ear) and male (tassel) flowers in separate places on the plant. The maize grain develops in the ears, or cobs, often one on each stalk; each ear has about 300 to 1 000 kernels. Following Eicher & Byerlee (1997), maize grain's weighing is between 190 and 300 g per I 000 kernels, in a variable number of rows (12 to 16). Weight depends on genetic, environmental and cultural practices. Maize grain makes up about 42 percent of the dry weight of the plant. The maize grain kernels are often white or yellow in colour, although black, red and a mixture of colours are also found. Also, there are a number of grain types, distinguished by differences in the chemical compounds deposited or stored in the kernel(Eicher & Byerlee 1997).

As described respectively in Figure 1 below, the major parts of the maize kernel are the endosperm and the germ, which contain most of the starch and oil

Figure 2. Cross-section of Maize grain



Source: Shukla &Cheryan, 2001

2.2 Physico-chemical properties

A. Moisture sorption

Moisture sorption and water activity are of particular importance in determining product quality and safety. Therefore, Water activity influences color, odor, flavor, texture and shelf-life of many products. Also, It predicts safety and stability with respect to microbial growth, chemical and biochemical reaction rates, and physical properties(Labuza et al., 1985).

The sorption of water vapour by maize grain has also received much attention because of its importance in dehydration processes and in changing of quality during storage. These changes in chemical, physical and biological properties of maize, which do not appear to be related directly to either moisture content or Aw, often can be explained in terms of the interrelationship between the two parameters expressed as a moisture sorption isotherm. The changes in isotherm characteristics, related to temperature, provide insight into the physical and chemical changes that influence Maize grain quality and stability (Sing et al., 2006b).

B. Maize lipids

The major classes of lipids includes: free fatty acids, triacylglycerols (triglycerides) consisting of fatty acids esterified to glycerol, and phosphoglycerides consisting of fatty acids esterified to glycerol and containing phosphoric acid and organic bases (Frankel, 2005). The free lipids are portions easily extractable with non polar solvents such as petroleum ether, hexane and diethylether by a Soxhlet extractor or by shaking.

Deterioration in the quality of maize during storage could be attributed to lipolysis and lipid oxidation. As reported by Sammon (1999) freeing of fatty acids takes place from the time of milling, presumably due to mixing of natural lipases with esterified fatty acids. Also considering Castello et al. (1998), the wheat and fungal lipases have been implicated in the increase of free fatty acids during long term storage of maize. Several reports for food studies have increases in free fatty acids during storage, for instance, in wheat flour (Castello et al., 1998) and in pistachio nut paste (Gamli & Hayoglu, 2007).

C. Microbiological quality of maize grain

Cereals ordinarily are not processed to greatly reduce their natural micro flora.
Consequently, these products can contain molds, yeasts, and bacteria, which will grow if enough moisture is added. A small amount moistening will permit growth of molds only, whereas more moisture will allow yeasts and bacteria to grow. In General, the natural micro-flora of maize meal does not constitute a spoilage problem in themselves because moisture content is too low to support even the growth of molds. However, temperature and moisture for cereals storage may be critical factors affecting quality**.** In a cereal storage study of maize meal, the predominant microorganism molds identified in maize meal were *Aspergillus glaucus* and *Aspergillus candidus*. Also a few species of *pencillium* and *Fusarium* were also observed (Bothast et al., 1981).

2.3 Maize plant development

Following Udo (2005), the maize plant may be defined as a metabolic system whose end product is mainly starch deposited in specialized organs, the maize kernels.

The development of the plant may be divided into two physiological stages. In the first or the vegetative stage, different tissues develop and differentiate until the flower structures appear. The vegetative stage is made up of two cycles. In the first cycle the first leaves are formed and development is upward. Dry matter production in this cycle is slow. It ends with the tissue differentiation of the reproductive organs. In the second cycle the leaves and reproductive organs develop. This cycle ends with the emission of the stigmas.

The second stage, also known as the reproductive stage, begins with the fertilization of the female structures, which will develop into ears and grains. The initial phase of this stage is characterized by an increase in the weight of leaves and other flower parts. During the second phase, the weight of the kernels rapidly increases (Eicher&Byerlee 1997).

Maize kernels develop through accumulation of the products of photosynthesis, root absorption and metabolism of the maize plant on the female inflorescence called the ear. This structure may hold from 300 to 1 000 single kernels depending on the number of rows, diameter and length of the cob. Kernel weight may be quite variable, ranging from about 19 to 40 g per 100 kernels. During harvest the ears of maize are removed from the maize plant either by hand or mechanically. The husks covering the ear are first stripped off, then the kernels are separated by hand or, more often, by machine(Eicher & Byerlee 1997)

2.4 Maize harvesting and postharvest techniques

A. Time to harvest

Maize can store for a considerable period in unprocessed form without undergoing deterioration. Its shelf life greatly depends on the prevailing ambient temperature and relative humidity, and other factors like the inherent moisture pests and diseases. Therefore, recommended post harvest handling and managing operations involve the manipulation of the above factors in order to obtain high quality maize grains.Quality control starts with harvesting. Harvesting is the single deliberate action to separate the cob from its grown medium. The optimum time of harvesting maize is when the stalks have dried and moisture of grain as about 20-17%.

B. Activities before harvesting

Considering the need for a farmer to keep the cobs clean, and also to dry the cob immediately and avoid infestation of the harvested cobs, as described by Bridge et al. (2005), a farmer makes the following preparations:

- Make sure the drying place or equipment is clean and disinfected, ready to receive the cobs.
- Remove old grain and dirt from anything that will come in contact with the good or new grain. This includes harvesting tools, carts, wheel barrows, bags and baskets.
- Where possible, fumigate them or at least treat them with boiling water to kill insects or their eggs. This is done in order to avoid infection of new grain by insects and their eggs.
- Organize enough labor to reap and carry the cobs to the drying place.

C. Harvesting

Following the same author, Bridge et al. (2005), here are requirements during the harvesting process:

- Harvest maize as soon as it is dry but not overstay in field it will be attacked by weevils if does and lodge. In addition to reducing post harvest losses, this will also release the field for early land preparation.
- Keep the grain as clean as possible. Dry maize on cement floor or use tarpaulin to reduce chance of contamination.
- At home, do not first heap the cobs in any room, kitchen or in the yard because this will expose them to all the dangers that cause post harvest losses. Transfer them to the drying place (like the crib) immediately.
- Dry on concrete or canvas not on bare soil

2.5 Maize drying

Following Ismail 2009, after harvesting, the greatest enemy of grain is moisture. Wet grains and attract insects and mould. Therefore, the grain must be dried as soon as possible after harvesting. The drying is the systematic reduction of crop moisture down to safe levels for storage, usually 12%-15.5% moisture content. It is one of the key post-harvest operations since all down-stream operations depend on it.

Drying permits the escape of moisture from grain moisture to an acceptable level, which can sustain very low metabolism. The enzyme activities and grain tissue respiration is reduced to a very low level, thus inhibiting sprouting/germination. During drying, the dry air rapidly takes moisture away from the grain, especially if the air is moving and has got low humidity. Grain can be dried in a crib before shelling and on tarpaulins after it has been shelled, Grain that is in contact with the ground will absorb moisture and pick up dirt and insects. Drying maize on plastic sheets or mats is becoming a common practice with farmers who are trying to keep maize off the groundduring drying. This practice is discouraged because of the following reasons:

- Someone should watch the grain while it dries.
- At night or when it rains, the grain must be brought under shelter.
- Grain can be washed away in case of a sudden down pour.
- Risk of contamination from dusts, soil, stones, animal droppings, fungal and insect infestation.
- Losses from birds, poultry and domestic animals, resulting into contamination and quantitative losses.
- The method is time consuming and labor intensive involving lots of grain handling. (Ismail 2009).

2.6 Maize shelling (threshing)

The most traditional system for shelling maize is to press the thumbs on the grains in order to detach them from the ears. This method requires a lot of labor, however It is calculated that a worker can hand-shell only a few kilograms an hour. Maize can also be shelled by rubbing the ears or heads on a rough surface. Small tools, often made by local artisans, are sometimes used to hand-shell maize. With these tools, a worker can shell 8 to 15 kg of maize an hour (Berenbaum, 1995). Shelling is also commonly done by beating maize cobs with stick in a sack or a confined floor space where farmers can afford it. It is better to use a maize shelter; beating maize will result in physical damage which makes it more vulnerable to pests and moulds and damage to the germ. Using a maize shelter is preferred although it will not be afforded by most farmers.

2.6 Maize grain cleaning

The "Cleaning" process means the phase or phases of the post-harvest system during which the impurities mixed with the grain mass are eliminated.

After threshing, grains (or shells, in the case of groundnuts) are contaminated by impurities (earth, small pebbles, plant and insect waste, seed cases, etc.).

These impurities hinder drying operations and make them longer and more costly. After drying, especially by traditional methods such as open-air drying, the grain may still be contaminated by impurities.These impurities lower the quality of the product and are also a focal point for potential infestation during storage.

This operation, which may be accompanied by a sorting of the products according to quality, is indispensable before storage, marketing or further processing of the products.It is also necessary as an operation preliminary to artificial drying of the products in dryers.

Indeed, it would be not only costly but also superfluous to waste time, effort and money on drying the impurities along with the grain. (Pingali & Pandey, 2000)

2.7 MAIZE STORAGE

2.7.1 Definition and objectives of storage

"Storage" means the phase of the post-harvest system during which the products are kept in such a way as to guarantee food security other than during periods of agricultural production.

The main objectives of storage can be summed up as follows:

- at the food level, to permit deferred use (on an annual and multi-annual basis) of the agricultural products harvested;
- at the agricultural level, to ensure availability of seeds for the crop cycles to come;
- at the agro-industrial level, to guarantee regular and continuous supplies of raw materials for processing industries;
- at the marketing level, to balance the supply and demand of agricultural products, thereby stabilizing market prices

2.7.2 Factors which influence qualitative and quantitatives parameters of maize storing

As it was outlined by Meikle et al.(2002), it is necessary to adopt measures aimed at preserving the quality and quantity of the maize stored products over time.

- ***Influences of environmental factors***

To conserve the quality of products over long-term storage, degradation processes must be slowed down or even stopped.

Following Markham et al. (1994); Oduor et al. (2000); degradation of grains during storage depends principally on a combination of three factors:

- temperature,
- moisture,
- oxygen content.

During storage, as during other phases of the post-harvest system, the combined effects of these three factors can sometimes cause severe losses.

A. Temperature and moisture

Temperature and moisture are determining factors in accelerating or delaying the complex phenomena of the biochemical transformation (especially the "breathing" of the grain) that are at the origin of grain degradation.(Markham et al., 1994; Oduor et al., 2000)

Furthermore, they have a direct influence on the speed of development of insects and microorganisms (moulds, yeasts and bacteria), and on the premature and unseasonal germination of grain.

In the general diagram of conservation designed by Burges and Burrel, the relationship between temperature and moisture content is established in order to determine the area of influence of certain important degradation phenomena, such as: the development of insects and moulds, and the germination of grain.It is easy to observe that the higher the temperature, the lower must be the moisture of the grain in order to ensure good conservation of the products.

In view of their influence on the speed of development of these degradation phenomena, the temperature and moisture content of the grain condition the maximal duration of storage.

Table 3 Duration of warehousing (in days)

	TEMPERATURE (^oC)					
MOISTURE (%)	**5°C**	**10°C**	**15°C**	**20°C**	**25°C**	**30°C**
13%				180	115	90
14%			160	100	50	30
15%			100	50	30	15
16%		130	50	30	20	8
17%		65	35	22	12	5
18%	130	40	25	17	8	2
19%	70	30	17	12	5	0
20%	45	22	15	8		
21%	30	17	11	7		
22%	23	3	8	6		
23%	17	10	7	5		
24%	13	8	4	4		
25%	10	8	6	3		

Source: Pingali & Pandey (2000).

As an example, the preceding table shows the recommended durations of warehousing, according to the temperature and moisture content of the grain.

The temperature depends not only on climatic conditions but also on the biochemical changes that are produced inside a grain mass, provoking undesirable natural heating of the stored products.

As for the moisture content of the stored grain, it depends on the relative humidity of the air, as shown in the air-grain equilibrium curves.

With a relative air humidity below 65-70 percent, many grain-degradation phenomena are slowed down, if not completely blocked.

In this sense,as mentionned by Markham et al. (1994); Oduor et al. (2000), the "safeguard" moisture content is defined as that corresponding to an equilibrium with the air at 65-70 percent relative humidity.

Table 4 The moisture content recommended for long-term storage in hot regions of various sorts of grain.

GRAIN	**MOISTURE**	**GRAIN**	**MOISTURE**
Paddy	14.0%	Sunflower	9.0%
Rice	13.0%	Wheat	13.0%
Maize	13.0%	Millet	16.0%
Sorghum	12.5 %	Coffee	13.0%
Beans	15.0%	Cocoa	7.0%
Groundnut	7.0 %	Copra	7.0 %

Source: Pingali & Pandey (2000)

B. Oxygen content

Like grain, micro-organisms and insects are living organisms that need oxygen.

Storage of grain in places that are low in oxygen causes the death of insects, cessation of development of micro-organisms, and blockage, or slowing down, of the biochemical phenomena of grain degradation. This favours the conservation of grain, but may affect its germinating power. (Markham et al., 1994; Oduor et al., 2000)

2.7.3 Agents causing deterioration of stored grain

The principal enemies of stored grain are micro-organisms, rodents, and insects

A. Micro-organisms

A definition, Micro-organisms (moulds, yeasts, bacteria) are biological agents present in the soil which, when transported by air or water, can contaminate products before, during and after the harvest.

The presence and growth of Micro-organisms cause severe changes in the nutritive value and the organoleptic features of grain (taste, smell, aspect).

Furthermore, following Oduor et al., 2000, they are responsible for the alteration of important germinative properties of seeds (vigour and capacity to germinate) and, in the case of moulds, for the potential formation of dangerous poisons (mycotoxins).

Impurities, and cracked or broken grains, foster the development of micro-organisms.

It has been observed that micro-organisms develop at temperatures between -8°C and +80°C, when the relative humidity of the air is over 65 percent(Markham et al., 1994; Oduor et al., 2000).

B. Rodents

Rodents cause serious damage not only to stored products but also to packaging and even to storage buildings. They invade and multiply in or near storage places, where they can find an abundance of food.

The principal rodents, as described by Tapondjou et al.(2002), those most common and likely to attack stored products, belong to the following species:

- black rat, also called roof rat (Rattus rattus),
- brown or Norway rat, also called sewer rat (Rattus norvegicus),
- mouse (Mus musculus).

The prolonged attacks by rodents inevitably results in serious quantitative losses of stored products.

Also the filth (excrement, secretions) that rodents leave behind in the stored products,causes the decrease in quality of the foodstuffs.

C. Insects

Insects can be responsible for significant losses of product (Hell et aI.,2000a). Furthermore, their biological activity (waste production, respiration, etc.) compromises the quality and commercial value of the stored grain and fosters the development of micro-organisms.

The insect infestations can occur either in the field, before the harvest, or in the places where products are stored.

And sometimes, these infestations are difficult to discern with the naked eye, since the damage is provoked by the larvae developing inside the grain.

As mentioned by Park (2002), the insects most likely to infest stored products belong to the following families:

- *Coleoptera* (damage by larvae and adult insects);
- *Lepidoptera* (damage only by larvae).

and also they can live and reproduce at temperatures between +15°C and +35ºC.

Contrary, low humidity slows or even stops their development, and a low supply of oxygen rapidly kills them.

2.7.4 Storage techniques

Maize storage in bags and in bulk are basically two main methods of its storage. A big quantity of bags can be stored either in the open air or in warehouses; bulk grain is stored in bins or silos of various capacities. These methods and the degree of technological sophistication of the storage buildings depend on many technical, economic and socio-cultural considerations. (Morris, 2007).

There is also the traditional storage systems used by small farmers which must also be mentioned. they use artisanal construction techniques and local materials, and these are the systems that prevail in the rural communities of many developing countries.

A. Storage in bags

a. <u>Definition</u>

The method of storage in bags consists of conserving dried and cleaned grain in bags made of plant fibre or plastic, and neatly stacking the bags in carefully prepared areas; and this method is little used in developed countries but is widespread in developing countries. It is more economical and well-adapted to local grain-transport and marketing conditions (Acharya & Young, 2008).

We can consider several ways of storing grain in bags. Amost bags of grain can be stacked out-of-doors under tarpaulins, or placed inside storehouses, sheds or warehouses.

But sometimes, especially for seeds, grain is stored in bags in refrigerated warehouses.

b. ***<u>Outdoor storage</u>***

These are maize storage systems in which the bags are not stacked in solidly constructed buildings. The following are the main systems of open-air storage:

- storage in pyramids,
- storage in flexible silos.

➢ <u>Storage in pyramids</u>

This system of storage in pyramids is often used for short-term storage in dry areas. It consists of stacking bags pyramids on platforms that can be protected in case of bad weather.

Folowing Park (2002) the platforms on which the bags are stacked must effectively protect the grain against termite attacks.

These storage pyramids are mostly covered by concrete or tar or made up of a layer of building-blocks covered with tarpaulins or plastic, the platforms must prevent the grain from exposure to rising damp.

To keep rain-water from falling on the grain, it is important to cover the pyramids of bags with tarpaulins.

This technique of Storage in Pyramids is frequently used for groundnut storage.

- Storage in flexible silos

Fooling the same Author, Storage in flexible silos is often used for setting up a security reserve and is very similar to storage in pyramids, and the main difference is the greater complexity of the storage facility.

A flexible silo is made of a concrete platform. Generally walls of galvanized screening about 2.5 metres high are erected around it and the inner walls lined with a thick film of plastic. On the outside, it is about 50 cm from the walls, galvanized metal sheets about 1 m high surround the silo to protect the grain from rodent attacks.

Because these buildings are almost completely sealed, it is important to store the grain when it is very dry.

Flexible silos of 500 tonnes are the most common, but some are also built with storage capacities of 250 to 1 000 tonnes(Park, 2002). The costs of building these silos are fairly modest, but their useful life is relatively short, seldom exceeding five years.

c. Warehouses and storehouses

Whether simple huts that farmers have turned into storehouses or modern well-equipped warehouses, following Tom (2008) storage buildings must meet the following requirements:

- prevent the access of insects, rodents and birds to the storage places;
- facilitate monitoring of grain conservation;

- permit timely insecticide treatment of bags and premises;
- facilitate the care of equipment used to move and transport the bags.
- protect the grain from high temperatures;
- prevent the grain from getting wet;

Location and orientation of the buildings

Effective protection of stored grain against atmospheric factors (sun, rain, humidity) and smooth operation of storage systems depend on good location and alignment of the buildings.

In this respect, the buildings to be used for storage must be:

- located in relatively dry sites not prone to flooding; thus, low-lying areas, clayey or poorly drained soils, and proximity to streams and lakes must be avoided as much as possible;
- located outside towns and, if possible, in areas equidistant from agricultural production areas and near transport facilities;
- located, to the extent possible, near electricity and water distribution systems;
- aligned on a north-south axis so that the sides with the smallest area get the strongest sun.

Dimensions of the buildings

Storehouses are generally rectangular, about twice as long as they are wide. Appropriate dimensions of these buildings can be determined with a knowledge ofthe type, quantities and specific volume of grain to be stored in bags;the maximum height of the stacks of bags;the number of batches to be separated and the width of the access corridors; and also the extent and arrangement of service areas.

volume of Maize grain to be stored in bags

The specific volume means, for each type of grain, the space occupied by a tonne of product stored in bags. Its unit of measurement is the cubic metre per tonne of product (m^3/t).

Table 5 The specific volumes of some products stored in bags

GRAIN STORED IN BAGS	SPECIFIC VOLUME
Milled rice, wheat, coffee	1.6 m^3/t
Maize, sorghum, groundnuts	1 8 m^3/t
Beans, peas, lentils	1.3 m^3/t
Sunflower seeds	2.8 m^3/t
Soybeans, cocoa	2.0 m^3/t
Millet	1.25 m^3/t
Cottonseed	2.5 m^3/t
Wheat flour, maize flour	2.1 m^3/t

Source: Odeyemi et al.(2006)

By multiplying the specific volume (in m^3/t) by the quantity of grain (in t) to be stored, one obtains the volume (in m^3) occupied by the bags in the storehouse.

B. Bulk maize grain storage

A. Definition

The method Bulk maize grain storage consists of storing unpackaged grain in structures built for this purpose (bins, silos).

The types of construction of silos and bins vary. There can be simple low-capacity structures for storage of agricultural surpluses in production areas, or large complex installations for commercial or industrial storage of grain products.

In general, there are two categories of bulk-storage structures: low-capacity silos or bins for storage on the farm and high-capacity silos.

The latter, which are widely used in developed countries, are not yet very widespread in the developing countries (Odeyemi et al., 2006).

B. Low-capacity silos for farm storage

On-farm maize storage is the basic form of rural storage in many developing countries. involves only very small quantities of grain, mostly for only home consumption.

There are many types of traditional storage structures, each adapted to the climate of the country. The common feature of all of them is the use of locally available materials. For example, some are enclosed earthen granaries of the dry zones and the ventilated granaries made of plant fibre and wood that are used in humid zones.

In dry zones, as mentioned by Hell et aI. (2000a) the risks of stock degradation come mainly from insects and rodents, and they are generally lower than the risks in humid zones, where stocks are attached not only by these pests but also by moulds.

There are two possible approaches to lowering or prevent losses from pest attacks: improvements to traditional storage structures, and new structures built from non-traditional materials.

The first approach has produced improvements in the construction of earthen granaries (mixing small quantities of cement with the earth or careful finishing or smoothing of the silo walls).

The second one involves more innovative experiments in building small-capacity (1 to 2 tonnes) silos with bricks or breeze-blocks made of reinforced earth, or with mud or unbaked bricks.(Hell et aI., 2000a).

C. High-capacity silos

As described by Tom (2008), High-capacity silos are complex structures intended for the commercial or industrial storage of large quantities (several thousand tonnes).

Specialized builders offer various types of silos; two, in particular:

- vertical silos,
- horizontal silos.

Vertical silos are made up of several sheet-metal or reinforced concrete storage bins stacked vertically. This category includes silos composed of: round bins made of flat or corrugated galvanized sheet metal; polygonal bins made of painted or galvanized metal panels; round bins made of reinforced concrete.

Horizontal silos are also made of sheet metal or concrete and are composed of juxtaposed square or rectangular bins laid horizontally.

The relatively common round metal bins require less investment and are easy to erect.

Polygonal bins are similar to round ones and their diameters are easily adjustable.

Round concrete bins guarantee good thermal insulation and permit much higher vertical stacking than can be obtained with metal bins.

Square or rectangular bins are generally flat-bottomed. They require a higher per quintal investment but make the best use of the available sites.

In order to avoid the disadvantages of a potential rise in temperature, and to guarantee good storage, storage bins are often equipped with ventilation systems backed up by temperature controls. (Markham et al., 1994).

In terms of storage, these ventilation systems can have the following effects:

- to lower the temperature of the grain in order to slow down biochemical degradation processes (cooling ventilation);
- to keep the grain at a constant temperature, by systematically evacuating the heat produced by the grain mass itself (maintenance ventilation);
- to dry the grain slowly (drying ventilation).

In addition, again in order to guarantee good conservation of grain, special airtight silos store the products in the absence of oxygen, in a confined or controlled atmosphere.

In the first case, the oxygen inside the silo is consumed by the natural "breathing" of the grain, and the insects and micro-organisms, and is simultaneously replaced by the carbon dioxide produced by this breathing.

In the second case, once the airtight silo has been closed, the internal atmosphere is replaced by the injection of inert gasses (nitrogen, carbon dioxide).

Despite the obvious advantages of these storage systems, airtight silos still have limited distribution because of their technological complexity especially for the high-capacity bins (Markham et al., 1994; Oduor et al., 2000).

D. Equipping bulk-storage centres

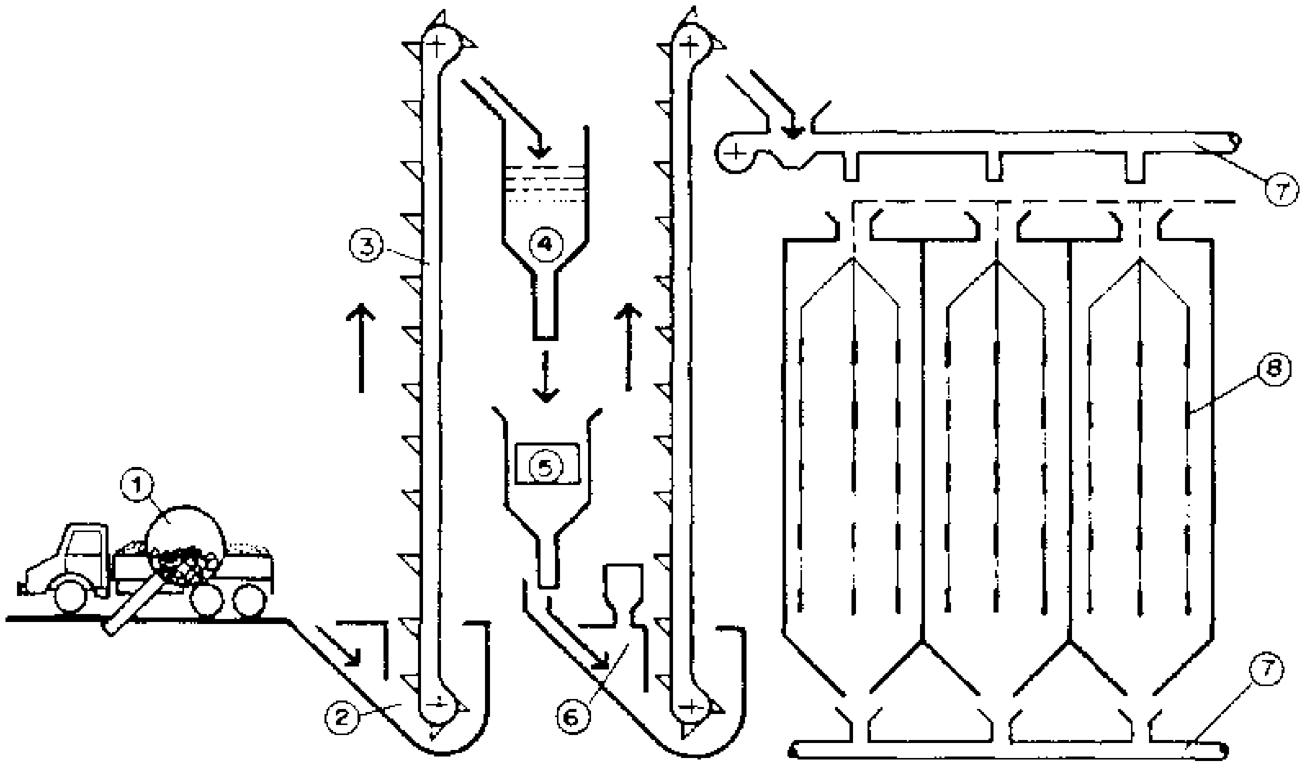
Considering the large quantities to be managed, again as considered by Tom (2008), bulk-storage centres should not only have silos of adequate capacity but should also possess equipment that can ensure quick and easy execution of the operations of receiving, treating, storing, monitoring and discharging grain.

Following Tapondjou et al.(2002), Equipment is selected on the basis of various factors, including:

- volume of storage capacity;
- number and size of bins;
- handling capacity (receiving, cleaning, ensiling, discharging);
- performance of drying equipment and ventilation devices;
- organization of work; economic return.

The Figure 3 below shows how a bulk-storage centre operates: Checking , Hopper , Vertical Handling, Cleaning, Waighing, Insecticide Treatment, Horizontal handling and Temperature Control.

Figure 3 Bulk-storage centre operation.



Source: Morris (2007)

1. Checking ,
2. Hopper ,
3. Vertical Handling
4. Cleaning
5. Waighing,
6. Insecticide Treatment
7. Horizontal handling
8. Temperature Control.

To ensure that storage centres operate smoothly, especially during stocking periods, particular attention must be given to the dimensions and type of equipment for receiving and handling the grain (Tapondjou et al.,2002).

2.8 Maize post harvest and storage techniques in Rwanda

2.8.1 Overview of the Rwandan Agriculture Sector

Following the Adapted from RADA Business Plan (2006-08), Rwanda's total arable land is about 1.4 million hectares (ha) which is 52 per cent of the total surface area of the country. There is potential for arable land expansion through the use of irrigation. The EDPRS aims to increase the area of hillside agricultural land under irrigation from130 ha in 2006 to 1,101 ha in year 2012. The area under food crops has been increasing from28,000 ha in season 2008 to 66,000 ha (2009) and 254,448 ha in 2010.

Table 6 Crop Production (2009)

Crop	**Area under the crop(ha)**	**Production (MT)**
Maize	106,976	88,210
Rice	12,167	46,191
Wheat	22,191	16,772
Beans	319,349	198,225
G/nuts	18,883	10,785
Peas	32,176	16,759
Soya Beans	36,707	18,300

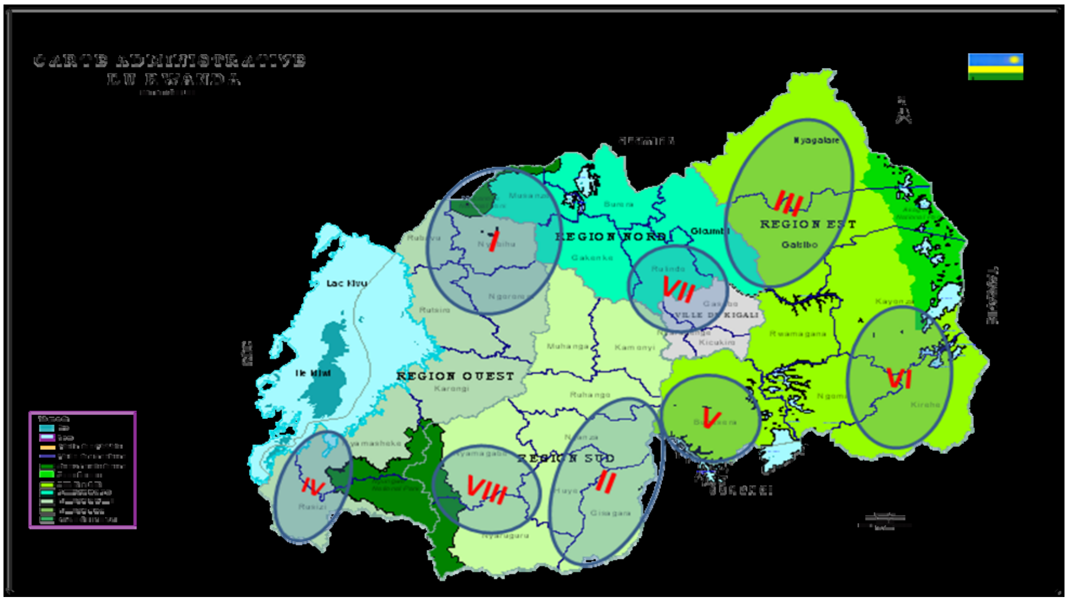
Source: Adapted from RADA Business Plan (2006-08)

2.8.2 Backgground of maize production in Rwanda

Maize, as a dried grain, is not a common traditional crop in Rwanda, having been grown in the past more for consumption of fresh maize cobs, and the stalks fed to livestock. Following the "Plan Stratégique pour la Transformation de l'Agriculture II" (PSTA II), and the launch of the Ministry of Agriculture and Livestock's Crop Intensification Program (ICP), maize production in Rwanda was strongly promoted and supported, and yields as well as volumes of maize produced in country have sharply risen over recent years (FAOSTAT, 2009)

According to the map of Rwanda below from the Enquête Agricole Nationale du Rwanda, 2008; the major production zones of staple crops in Rwanda are divided in 8 zones:

Figure 4 Major Production Zones of Staple Crops in Rwanda



Source : Enquête Agricole Nationale du Rwanda, 2008 (Tableau 4.2.2.)

Zone I, the north/northwestern part of Rwanda, is the major site of Irish potato production, and also has significant production of wheat, beans and maize. Zone II, in central-southern Rwanda, is characterized by large volumes of rice, cassava, maize, and a small amount of soybean production. Zone III, in northeastern Rwanda, produces large amounts of maize, cassava and beans. Southwestern Rwanda, Zone IV, has significant rice production, as well as some maize. Zone V, Bugesera, produces maize, cassava and beans, while southeastern Rwanda, Zone VI, produces large amounts of maize and some beans as a rotation. North-central Rwanda, Zone VII, produces Irish potato, beans, wheat and some maize. Finally, the south-central plateau, Zone VIII, produces wheat, beans and some maize

2.8.3 Cultivation

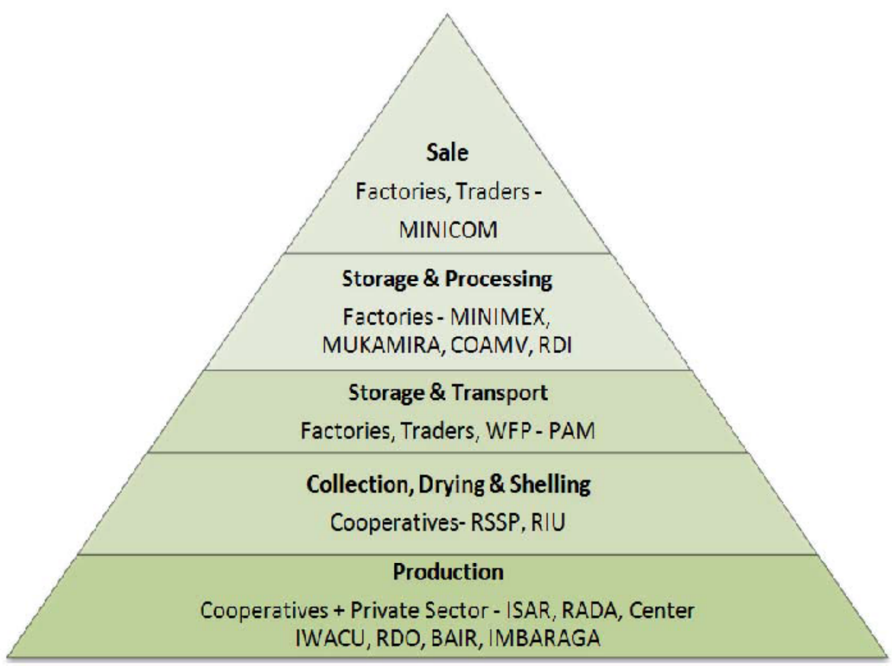
Much of Rwanda's maize production is concentrated in valley areas, many of which have been recently drained for crop production purposes. However, some maize is also grown on hillsides, usually with poorer results. The best production areas in terms of climate are found in eastern

Rwanda, where temperatures are higher and there is a longer dry season for drying the thick grain. Production in valley areas is greater during Rainy Season A, due to the risk of flooding in Rainy Season B, whereas hillside production predominates in the heavier Rainy Season B. Some valley areas with adequate moisture are used for maize production in the long dry season, Season C. Rainy season A falls from mid to lateSeptember to mid to late December, with maize harvest taking place in February-March; rainy season Bfalls from late February-early March to early June, with harvest taking place during Season C which islate June to early September.

2.8.4 Maize value chain

Currently, following the FAOSTAT (2009), there are different modalities of maize collection after being produced by Cooperatives and farmers themselves. Some maize producing cooperatives have no viable storage facilities, are located far from main roads and have to pay high prices for transporters to take their product to markets. More again no company or famers cooperative has yet become specialized in maize transport; traders either have their own trucks or use general goods transporters from within the region – Rwanda, Uganda and Tanzania.

Figure 5 Maize chain value in Rwanda



Source: FAOSTAT (2009)

2.8.5 Tradition maize postharvest operations in Rwanda

A. Harvesting

Following MINAGRI (November 2005) and as ullustrated by the figure below, the harvest operations in Rwanda are done by hand.the Harvestingof maize is done as soon as it is dry but not overstayed in field because it can be attacked by weevils. In addition it is done in order to reduce post harvest losses, and this will also release the field for early land preparation.

Figure 6 Woman harvesting maize manually

Source: Habimana (2013)

B. Drying

The maize grain is dried as soon as possible after harvesting. This is particularly so in some regions of Rwanda where humidity and rainfall remain high at harvesting delaying the harvest and constraining actual drying. Sometimes the next season starts early when the crops are still in the field, so the choice of varieties is crucial such that the farmers must be sure that a variety that they choose will mature and dry before the beginning of next season.

Figure 7 Farmers drying maize cobs in the sun

Source: Habimana (2013)

C. Maize Shelling (Threshing)

The most traditional system for shelling maize is to press the thumbs on the grains in order to detach them from the ears. This method requires a lot of labor, however It is calculated that a worker can hand-shell only a few kilograms an hour. Maize can also be shelled by rubbing the ears or heads on a rough surface

Figure 8 A famer is shelling manually the harvested maize

Source: Habimana (2013)

D. Maize grain Cleaning

The Common method used in Rwanda for grain cleaning, is the simplest cleaning one, known as winnowing (Figure 7), which consists of tossing the grain into the air and letting the wind carry off the lightest impurities.

Although widespread in farming circles, this cleaning method does not eliminate the heavier impurities (gravel, foreign grains, earth, etc.).

Figure 9 Women are cleaning maize by winnowing method

Source: Habimana (2013)

E. Maize storage

1. Traditional storage techniques in Rwanda

The Rwandan farmers generally store their grain in simple granaries constructed from locally available materials like paddy straw, split bamboo, reeds, mud and bricks. A majority of maize is stored in bags in a room, bin, drum or container for family consumption or is piled in farm buildings lacking proper flooring, closed doors and windows. Wheat is lost to moulds, birds, rodents, and insects. Storage varies in size and type including indoor, outdoor, above-ground, under-ground or airtight structures. Some conventional storage structures used by the farmers in Rwanda are:

1. Mud structures mostly bins or pots
2. Wood or Bamboo structures
3. Metallic drums, bins or containers
4. Straw structures

Figure 10 Rwanda's traditional technique of storing maize on airtight structures

Source: Habimana (2013)

2. Improved maize storage techniques

Some famers who got some training in Grain storage skills perform a little improved storage techniques. They maintain an even, cool and dry storage environment and they place bags of maize on pellets above the floor to avoid cold conditions that may lead to moulds

Figure 11 Improved Techniques of storing Sacks of maize off the floor

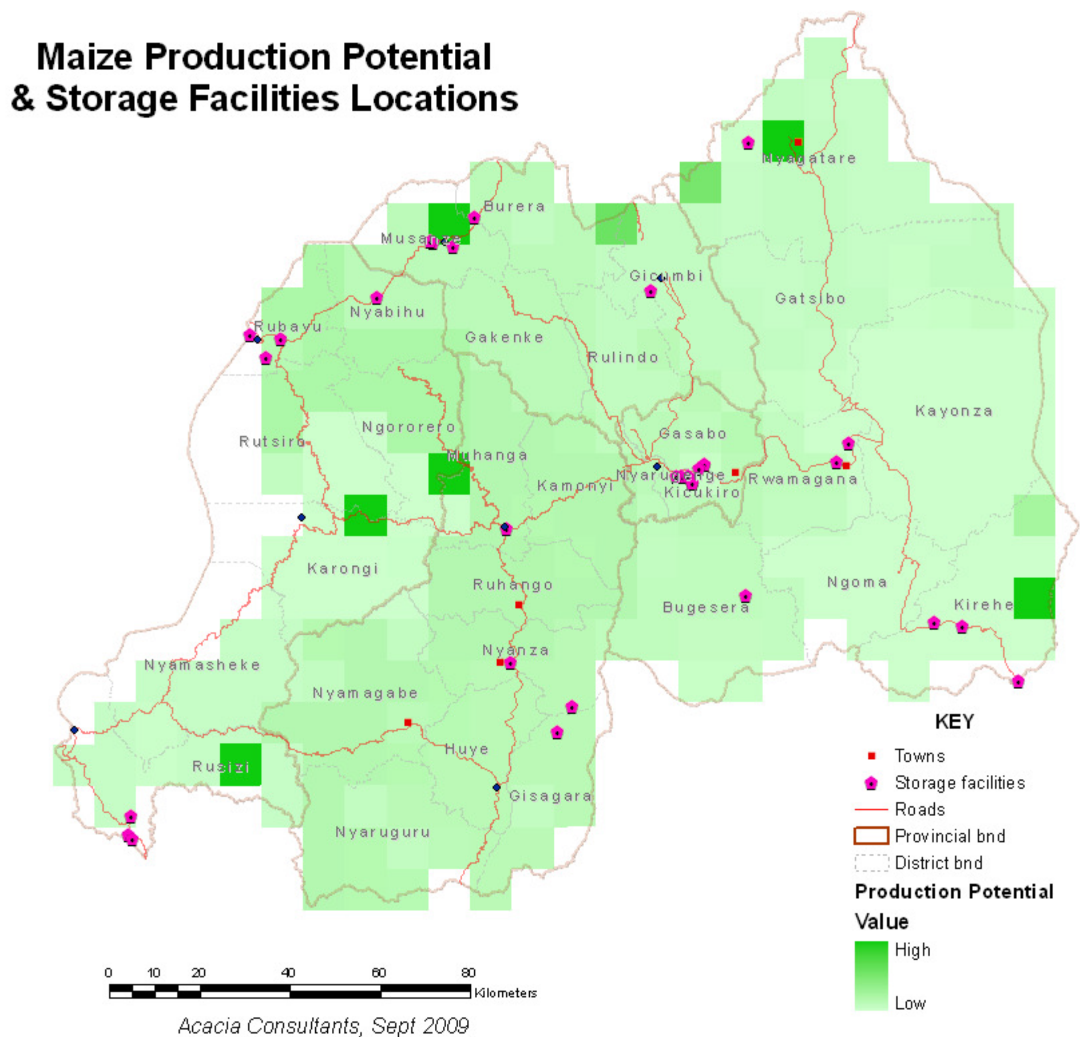
Source: Habimana (2013)

3. *Modern maize storage facilities*

Several programs have been launched by the Rwandan Government to address the deficit in post-harvest infrastructure, with varying degrees of success:

- Distribution of hermetically sealed Maize grain storage cocoons in the Eastern Province, in general without adequate provision of training, which has resulted in significant storage losses.
- Construction of storage silos with donor assistance (UNDP, WFP, IFAD, etc.).
- Rehabilitation of the pre-1994 strategic storage facilities.

Figure 12 Rwanda Maize Production Potential and Location of Storage Facilities



Source: ACDI/VOCA*(http://www.acdivoca.org).*

There were a total of 32 stores visited, distributed as follows: 9 inKigali City Province, 8 in Western, 7 in Eastern, 4 in Southern and 4 in Northern Provinces.

All those facilities comprise of warehouses, silos, depots and hermetic cocoons (used tomainly store maize and beans in the Eastern Province). Majority of them belonged to privatecompanies and co-operatives in premises they mostly owned and just a handful were rentedfrom individual premises or government institutions.

The main Rwanda's government achievment in terms of grain storage facilities, is the construction of the **National Strategic Grain Reserve,**

Figure 13 The Rwanda National Strategic Grain Reserve

Source: Habimana (2013)

3 AIMS OF THE THESIS

Focused on nutritive and technological aspects of maize storage,

General principles of maize storage techniques in Rwanda,

Optimization of maize post- harvest operations,

Possibilities of grain storage in controlled CO_2 atmosphere.

4 MATERIAL AND METHODOLOGY

4.1 Rwanda National Strategic Grain Reserve (NSR)

The grain maize sampling has been made from the Rwanda National Strategic Grain Reserve, and taken to Czech Republic. Therefore it is important to describe its main activities and achievement so far.

Rwanda National Strategic Grain Reserve(NSR)is a Rwandan Government institution working under the Ministry of Agriculture.This 3.5-year initiative started in September 2009 and addresses post-harvest inefficiencies by improving storage facilities and post-harvest practices. The institution‘s approach includes four components: market linkages, investment finance, post-harvest management and post-harvest policy strategy. These components work together to lead to a reduction in post-harvest losses; an increase in storage facilities; more farmers using storage facilities; private sector funds flowing into post-harvest projects; and an increase in the weight and value of commodities entering USAID-supported storage.

Currently, the maize storing infrastructures hold by the institution is the silos of a capacity of 20,000 Mt and the Warehouse of a capacity of 16,000 Mt. During the time of Grain samplling, 15,000 Mt of maize were stored by the institution.

Following are main activities of the Rwanda National Strategic Grain Reserve :

- Training of farmer’s cooperative in Post Harvest best practices,
- Post harvest best practices dissemination,
- Post harvest tools and equipment distribution,
- Post harvest losses survey,
- Construction of drying grounds in different districts,
- Construction of warehouses,
- Installation of metallic silos,

- Mobilization of private sector to build storage facilities (warehouse),
- National Strategic Grain Reserves development,

Despite the small time for which the institution has been working, it has already contributed much in terms of grain post-harvest and storage. Following are its main achievement in terms of grain storage in Rwanda:

- 133,621 farmers (maize, rice, beans, Irish potato and wheat farmers) were directly coached on post harvest best practices,
- 63,963 sheetings, 4,947 shellers and 782 hermetic grain storage bags have been distributed to farmers in order to minimize post harvest losses,
- Post harvest losses of maize and rice have been reduced from 32% to 9.24% and 25% to 15.2% respectively for season 2013A.
- 157 drying grounds, 42 warehouses and 4 metallic silos have been constructed across the country with a total storage capacity of 134,110 MT.

4.2 Use of material

In means of acquisition for material for this thesis, a total of 2 samples of maize grain have been collected from Rwanda and taken to Czech Republic for lab tests and Analysis

The samples are as following:

1. Maize grain season 2012
2. Maize grain Season 2013

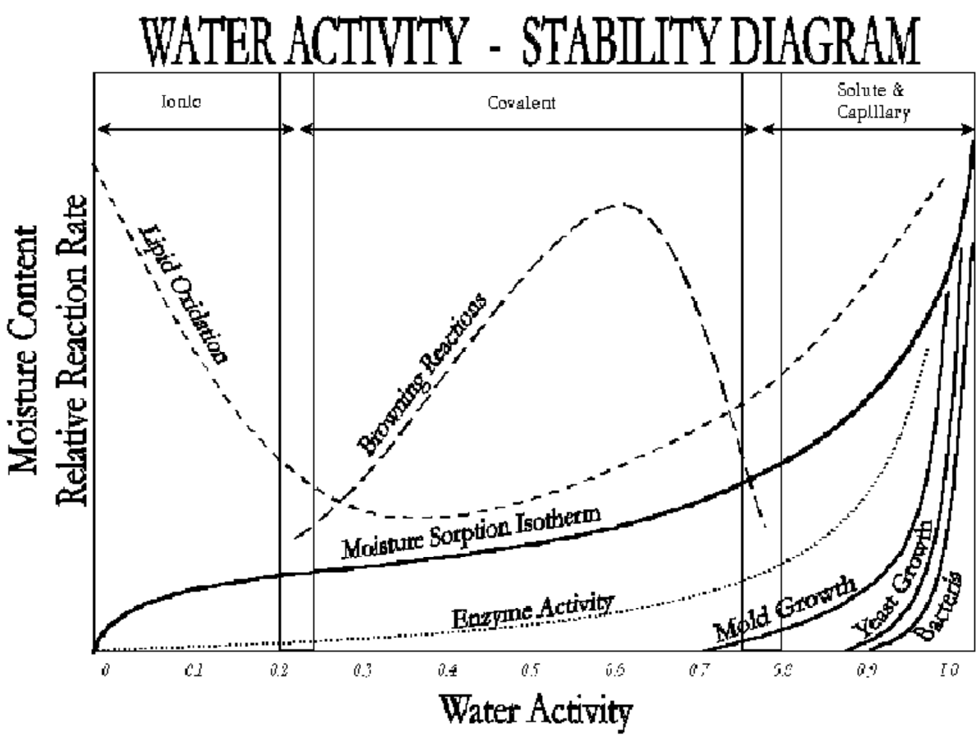
4.3 Product Samples

Samples of grain maize were taken from the Rwanda National Strategic Grain Reserve according to international standards. 250 g of Maize grain season A 2012 Sample and 250 g of Maize grain season B 2013 Sample were taken from the institution for analysis in Czech Republic. These two samples were analyzed in laboratories in Czech Republic and the results compared with other known results.

4.4 Water Activity analysis

Water activity (Aw) is a measure of the energy status of the water in a system, and also is a far better indicator of perishability than water content. *Figure 12* shows how the relative activity of microorganisms, lipids and enzymes relate to water activity. While other factors, such as nutrient availability and temperature, can affect the relationships, water activity is the best single measure of how water affects these processes as obtained by Rahman,(1995).The moisture isotherms for maize grain have been found to be temperature dependent as the equilibrium moisture content decreases with increase in temperature (Samapundo et al., 2007).

Figure 14 Standard diagram of water activity



Source: Labuza et al. (1985)

4.4.1 Sample preparation

To reduce the time needed to take a water activity reading for the coated and dried maize grain samples; both samples have been crushed (grinded) before putting them in the sample cup. This was done in order to increase the surface area of the sample, thus decreasing reading times from the Aqualab Model lab instrument. After Grain crushing, 4 maize grain samples for water Activity analysis were available:

1. Maize mill 2012 sample
2. Maize mill 2013 sample
3. Maize grain 2012 sample
4. Maize grain 2013 sample

4.4.2 Analytical method

After sampling, the water activity of the 4 maize samples was determined at room temperature using an electronic dew-point water activity meter, Aqualab Model Series 3(Decagon Devices Inc., Pullman, Washington, USA). The electronic equipment was calibrated with saturated salt solutions. The maize grain samples were placed in Aqualab sample dishes and immediately well covered with an Aluminium foil. The samples at high temperatures were left for not more than 15 minutes to equilibrate to room temperature before measurements were performed.

4.5 Biochemical Analysis

All samples were determined following chemical analysis:

1: Dry matter

2: Ash

2: Crude protein

3: Ether extract

4: Crude fiber

5: organic matter

6: iodine number

7: Nitrogen free extract

Analysis was performed in the laboratory of Czech University of Life Science (FAPPZ).

4.5.1 STANDARD OPERATING PROCEDURE

The standards operating procedures used in this chemical analysis are following the Commission Regulation (EC) no 152/2009 of 27 January 2009 from the European Community laying down the methods of sampling and analysis for the official control of feed.

A. DETERMINATION OF MOISTURE

Procedure

The operations described in this section must be carried out immediately after opening the packages of samples. Analysis must be carried out at least in duplicate.

4.6 PREPARATION

Take at least 50 g of the sample. Grind into particles of which at least 50 % will pass through a 0,5 mm mesh sieve and will leave no more than 10 % reject on a 1 mm round-meshed sieve.

4.7 DRYING

Weigh a container with its lid to the nearest 0,5 mg. Weigh into the weighed container, to the nearest 1 mg, about 5 g of the crushed sample and spread evenly.

Place the container, without its lid, in the oven preheated to 130 ^{0}C. To prevent the oven temperature from falling unduly, introduce the container as rapidly as possible. Leave to dry for two hours reckoned from the time when the oven temperature returns to 130 ^{0}C.

Replace the lid on the container, remove the latter from the oven, leave to cool for 30 to 45 minutes in the desiccators and weigh to the nearest 1 mg.

4.8 *PRELIMINARY DRYING*

Grain with a moisture content of over 17 % must be subjected to preliminary drying as follows:

Weigh 50 g of unground grain to the nearest 10 mg in a suitable container (e.g. a 20 × 12 cm aluminium plate with a 0,5 cm rim).

Leave to dry for 5 to 7 minutes in an oven at 130 ^{0}C. Remove from the oven, leave to cool uncovered in the laboratory for two hours and weigh to the nearest 10 mg.

Calculation of results

The moisture content (X), as a percentage of the sample, is calculated by using the following formulae:

a. *Drying without preliminary drying*

$$X = \frac{m - m_0}{m} \times 100$$

where:

m = initial weight, in grammes, of the test sample,

m_0= weight, in grammes, of the dry test sample.

b. *Drying with preliminary drying*

$$Xp = \{\frac{(m_{2-m_0}) \times m_1}{m_2} + m - m_1\}$$

where:

m = initial weight, in grammes, of the test sample,

m1 = weight, in grammes, of the test sample after preliminary drying,

m2 = weight, in grammes, of the test sample after crushing or grinding,

m0 = weight, in grammes, of the dry test sample.

c. Repeatability

The difference between the results of two parallel determinations carried out on the same sample shall not exceed

0,2 % of the absolute value of moisture.

d. Observation

If crushing proves necessary and if this is seen to alter the moisture content of the product, the results of the analysis of the components of the feed must be corrected on the basis of the moisture content of the sample in its initial state.

B. DETERMINATION OF CRUDE ASH

Procedure

Weigh out to the nearest mg approximately 5 g of the sample in the case of products which have a tendency to swell) and place in a crucible for ashing which has first been heated at 550 ^{0}C, cooled down and tared.

Place the crucible on the hot-plate and heat gradually until the substance carbonises.

Put the crucible into the calibrated muffle furnace set at 550 ^{0}C.

Keep at this temperature until white, light grey or reddish ash is obtained which appears to be free from carbonaceous particles.

Place the crucible in a desiccator, leave to cool and weigh immediately. Put the crucible into the calibrated muffle-furnace set at 550 ^{0}C. Ash for 3 hours.

Place the crucible in a desiccator, leave to cool and weigh immediately.

Ash again for 30 minutes to ensure that the weight of the ash remains constant (loss in weight between two successive weightings must be less than or equal to 1 mg).

a. Calculation of results

Calculate the weight of the residue by deducting the tare. Express the result as a percentage of the sample.

b. Observations

The ash of substances which are difficult to ash must be subjected to an initial ashing of at least three hours, cooled and then a few drops of 20 % solution of ammonium nitrate or water added to it (carefully, to avoid dispersal of the ash or the formation of lumps). Continue calcining after drying in the oven. Repeat the operation as necessary until ashing is complete.

C. DETERMINATION OF THE CONTENT OF CRUDE PROTEIN

Procedure

a. *Digestion*

Weigh 1 g of the sample to the nearest 0,001 g and transfer the sample to the flask of the digestion apparatus.

Add 15 g of potassium sulphate , an appropriate quantity of catalyst 0,3 to 0,4 g of copper (II) oxide or 0,9 to 1,2 g of copper (II) sulphate pentahydrate, 25 ml of sulphuric acid and if required, a few granules of pumice stone and mix.

Heat the flask moderately at first, swirling from time to time if necessary until the mass has carbonised and the foam has disappeared; then heat more intensively until the liquid is boiling steadily. Heating is adequate if the boiling acid condenses on the wall of the flask. Prevent the sides from becoming overheated and organic particles from sticking to them.

b. *Distillation*

Add carefully enough water to ensure complete dissolution of the sulphates. Allow to cool and then add a few granules of zinc, if required.

Place in the collecting flask of the distillation apparatus an exactly measured quantity of 25 ml of sulphuric acid depending on the presumed nitrogen content.

Add a few drops of methyl red indicator

Connect the digestion flask to the condenser of the distillation apparatus and immerse the end of the condenser in the liquid contained in the collecting flask to a depth of at least 1 cm.

Slowly pour 100 ml of sodium hydroxide solution into the digestion flask without loss of ammonia.

Heat the flask until the ammonia has distilled over.

c. *Titration*

Titrate the excess sulphuric acid in the collecting flask with sodium hydroxide solution depending on the concentration of the sulphuric acid used, until the end-point is reached.

d. Calculation of results

The content of crude protein, expressed as a percentage by weight, is calculated according to the following formula:

Content of crude protein $=\frac{(V_0-V_1)\times C\times 0.014\times 100\times 6.25}{m}$

where:

Vo = is the volume (ml) of NaOH used in the blank test,

V1 = is the volume (ml) of NaOH used in the sample titration,

c = is the concentration (mol/l) of sodium hydroxide,

m = is the weight (g) of sample.

c. Verification of the method

1. *Repeatability*

The difference between the results of two parallel determinations carried out on the same sample must not exceed:

— 0,2 % in absolute value, for crude protein contents of less than 20 %,

— 1,0 % relative to the higher value, for crude protein contents from 20 % to 40 %,

— 0,4 % in absolute value, for crude protein contents of more than 40 %.

2. *Accuracy*

Carry out the analysis (digestion, distillation and titration) on 1,5 to 2,0 g of acetanilide in the presence of 1 g of sucrose 1 g acetanilide consumes 14,80 ml of sulphuric acid. Recovery must be at least 99 %.

d. **Observations**

Apparatus may be of the manual, semi-automatic or automatic type. If the apparatus requires transference between the digestion and distillation steps, this transfer must be carried out without loss. If the flask of the distillation apparatus is not fitted with a dropping funnel, add the sodium hydroxide immediately before connecting the flask to the condenser, pouring the liquid slowly down the side.

D. DETERMINATION OF VOLATILE NITROGENOUS BASES

Procedure

Weigh 10 g of sample to the nearest 1 mg and place with 100 ml of water in a 200 ml graduated flask.

Mix or stir in the tumbler for 30 minutes.

Add 50 ml of trichloroacetic acid solution , make up to volume with water, shake vigorously and filter through a pleated filter.

Using a pipette, introduce 1 ml of boric acid solution into the central part of the Conway cell and 1 ml of the sample filtrate into the crown of the cell.

Cover partially with the greased lid.

Drop 1 ml of saturated potassium carbonate solution quickly into the crown and close the lid so that the cell is airtight.

Turn the cell carefully rotating it in a horizontal plane so that the two reagents are mixed. Leave to incubate either for at least four hours at room temperature or for one hour at 40 ^{0}C.

Using a microburette titrate the volatile bases in the boric acid solution with sulphuric acid.

Carry out a blank test using the same procedure but without a sample to be analysed.

a. Calculation of results

1 ml of H2SO4 0,01 mol/litre corresponds to 0,34 mg of ammonia. Express the result as a percentage of the sample.

b. Repeatability

The difference between the results of two parallel determinations carried out on the same sample shall not exceed:

— 10 %, in relative value, for ammonia contents of less than 1,0 %,

— 0,1 %, in absolute value, for ammonia contents of 1,0 % or more.

c. Observation

If the ammonia content of the sample exceeds 0,6 %, dilute the initial filtrate.

4.6. Maize grain storage in controlled CO_2 atmosphere

Storage of grain in CO_2 controlled atmosphere is a modern cost-effective method for obtaining high-quality grain storage effect. Thus,with this grain storage techniques, grain and corn harvested with higher moisture up to 35 % are for example after a year of storage almost zeros content of fungi and bacteria.

This issue was addressed in a this research project.

B. Which food grains can be stored in this way and what are the requirements for their quality at harvest:

Maize is preferred to be harvested at a high humidity up to 35 %.

Wheat can be harvested and stored up to 20% moisture.

Peas and other legumes are harvested and stored at full maturity.

Very important is the correct and fast fermentation, which after filling and closing the storage area must take up to 10 days.

In the case of low concentration of carbon dioxide in the storage area, It can hapen the shielding of gas from cylinders.

C. Principle of grain storage in controlled CO_2 atmosphere

Basic and critical condition for grain storage in controlled CO_2 atmosphere is airtight.

Tanks , silos and towers may be made of steel , enamel , reinforced concrete or other material , or stack size not important , what is decisive is their hermeticity .

For this purpose, it can be used with a hopper tanks, conical bottom with a flat bottom.

Stacking grain is done from income trays (baskets) bucket elevator and gravity pipelines, projectile or pneumatic manipulator.

The picking beans are usually used stainless steel screw conveyor at the bottom of the tray. This screw conveyor is usually mounted on the outside of the airtight seal (flap) .

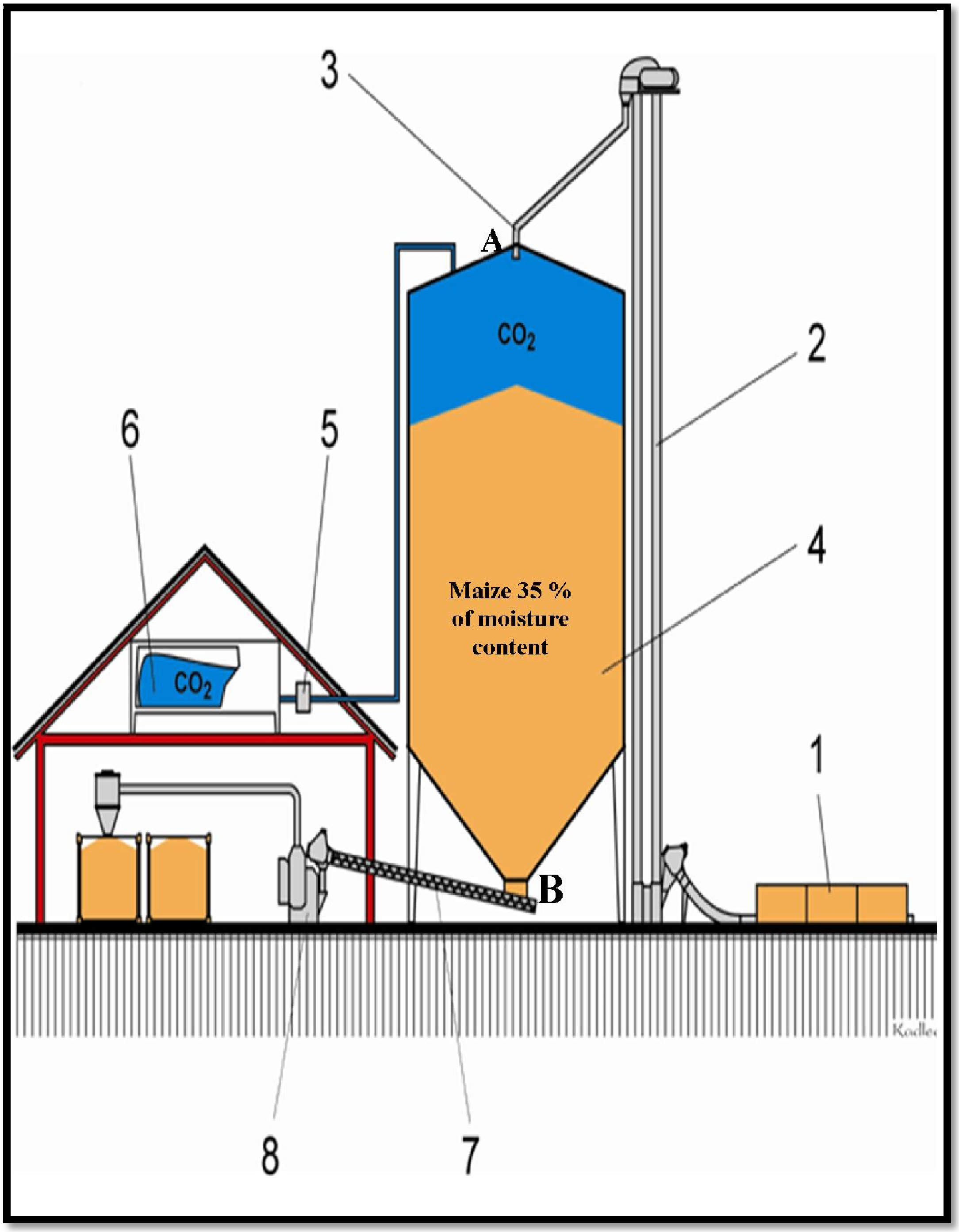
All grains are stored in the storage space, so that the parts of the grains with intact germ are immediately removed after loading O_2 , and also by the natural way of using lactic acid to prevent reproduction of bacteria.

Balancing bag used to capture excess amounts of CO_2 . Regulating the storage space and the bag ensures multiregulator - control valve.

If during picking pressure drops below 0.03 MPa, the pressure of carbon dioxide is automatically replenished from the reservoir via the control valve.

Other grains are dependent on the method for further processing , they are usually fully automated , computer-controlled .

Figure 15 The schematic diagram showing the entire processing line storage and processing of feed grain using a grain storage in CO_2 controlled atmosphere.



Source: Habimana (2013)

1 - the receive buffer

2 - bucket elevator

3 - manifold

4 - tower tank (silo)

5 - pressure relief valve

6 - bag

7 – Screw conveyor

8 – shredding

5 RESULTS AND DISCUSSION

A. Measurement results from maize grain samples

As illustrated by Table 7, the Water activity results have been obtained from the all samples, and respectively are as following: Maize mill 2012 Season (0.582) , Maize mill 2013 Season sample (0.650), Maize grain 2012 season sample (0.534), Maize grain 2013 Season(0.645)

Table 7 Measurement results for water activity in all samples

Maize Samples results	**Obtained water Activity (Aw)**	**Cereals Standars water activity**
Maize mill 2012 Season sample	0.582	0.60-0.50
Maize mill 2013 Season sample	0.650	0.60-0.50
Maize grain 2012 season sample	0.534	0.60-0.50
Maize grain 2013 Season sample	0.645	0.60-0.50

Source: Habimana (2013)

Considering Park (2002), the distribution of food by water activity values is as following:

1,00-0,90 high moisture foods,
0,90-0,60 intermediate moisture foods,
<0,60 Low moisture foods.
and the the standard water activity for cereals 0.60-0.50

The difference in water activities between maize mill and maize grain resides from the fact that the maize grains have a soft center and a hard outer coating. The water activity reading for the center and the outer coating are different. For this test, it has been necessary to crush one sample from the 2013 season, and one sample from the 2012 season. therefore, the water activity obtained from the crushed samples represent the average water activity of the entire sample;

whereas the non crushed samples give a reading for the coating, which may act as a barrier to the center.

In general, There was no significant difference in the evolution patterns of Aw for the control samples (the standard water activity for cereals 0.60-0.50) and 2012 Season samples measured in this project.

Table 8 Biochemical results for all samples

	Maize 2012 Season sample	Maize 2013 Season sample
ACTUAL DRY MATTER		
Dry Matter	88.98	88.66
Ash	1.05	0.82
Crude protein	9.20	8.87
Ether extract	4.09	4.407
Crude fiber	2.56	3.18
Organic matter	87.93	87.84
Nitrogen Free Extract	72.08	71.73
Correction factor	1.12	1.13
DRY MATTER 100%		
Dry Matter	100	100
Ash	1.18	0.93
Crude protein	10.34	10.00
Ether extract	4.60	4.59
Crude fiber	2.88	3.58
Organic matter	98.8	99.07
Nitrogen Free Extract	81.01	80.90

Source: Habimana (2013)

On the other hand for the control of 2012 Season samples, shows an increased to higher water activity values than for the control samples. this interference can be explained by the used technology of hermetically cereals storage in silos in tropic countries; but also by the lack of efficient drying techniques and infrastructures.

- **Interferences related to the hermetically storage of cereals in tropic countries**

In the tropics average temperatures are generally around 30^{o}C and the relative humidity fluctuates between 70-90%. The water vapor capacity of this warm and humid air is high, and particularly when the headspace heats to 50^{o}C. This air, at a relative humidity of 65%, may contain as much as 62g of water per m^3 air. When this air cools to a temperature of 30 ^{o}C, its maximum water vapor capacity drops to 29 g water/ m3 air. The excess of water vapor condenses on the roof (inside the silo) and each m^3 air releases about 33 g of water for each day/night cycle. Although day and nighttime temperature differences are very limited in tropical climates (usually not more than 5^{o}C), the problem arises due to heating of air at the headspace of the silo. The exposed metal roof temperatures can easily heat up to 60 ^{o}C or more, aggravating the condensation. Therefore, a commodity stored at 14% MC (at 70% RH) in a silo in the tropics is exposed both to high relative humidity and high temperature. Operation of the ventilation system is generally ineffective since the cooling effect of air with a day/night temperature difference of 5 ^{o}C is extremely low. In addition the ventilation system helps to expose the commodity to air with a high relative humidity (RH), thus increasing the MC of the commodity.

The Figure A in Appendix shows the factors having an impact on Bulk stored grain

As a result, insects easily develop in the grain (optimal temperatures for storage pest development is 28-35 ^{o}C). In addition, when the MC increases, molds and related aflatoxin easily develop.

The commodity should be stored dry at a safe moisture content (MC). For corn, this is set at 12.0% (which is in equilibrium with 60% relative humidity) because molds develop at higher relative humidities.

Problems of metal or concrete silos for long-term storage in the tropics:
In tropical climates, even if the commodity is sufficiently dry, it suffers from two major problems if stored within metal or concrete silos:

1. Condensation occurring below the roof of the silos and at the top layers of the grain bulk, leading to fungal and insect growth.

2. Contamination with fumigants and chemical contact insecticides necessarily used to prevent insect infestation.

B. **Results of the hermitically closed silos and the CO_2 content during grain storage in CO_2 controlled atmosphere**

To obtain high-quality raw materials for the production of compound feed is important that the entire storage period to ensure a sufficient level of CO_2 in the entire storage area.

In our experiments we observed four commodities, namely:

- Maize harvest moisture of 33-35%
- Corn with moisture adjusted to 23%
- Field pea
- Feed wheat about 19% moisture.

Storage time was from 60-to 420-days.

The results shown in the table document that even after a very long storage time, it is possible to maintain the perfect tightness of the stack very high concentrations of CO_2.

Storage time was from 60-to 420-days.

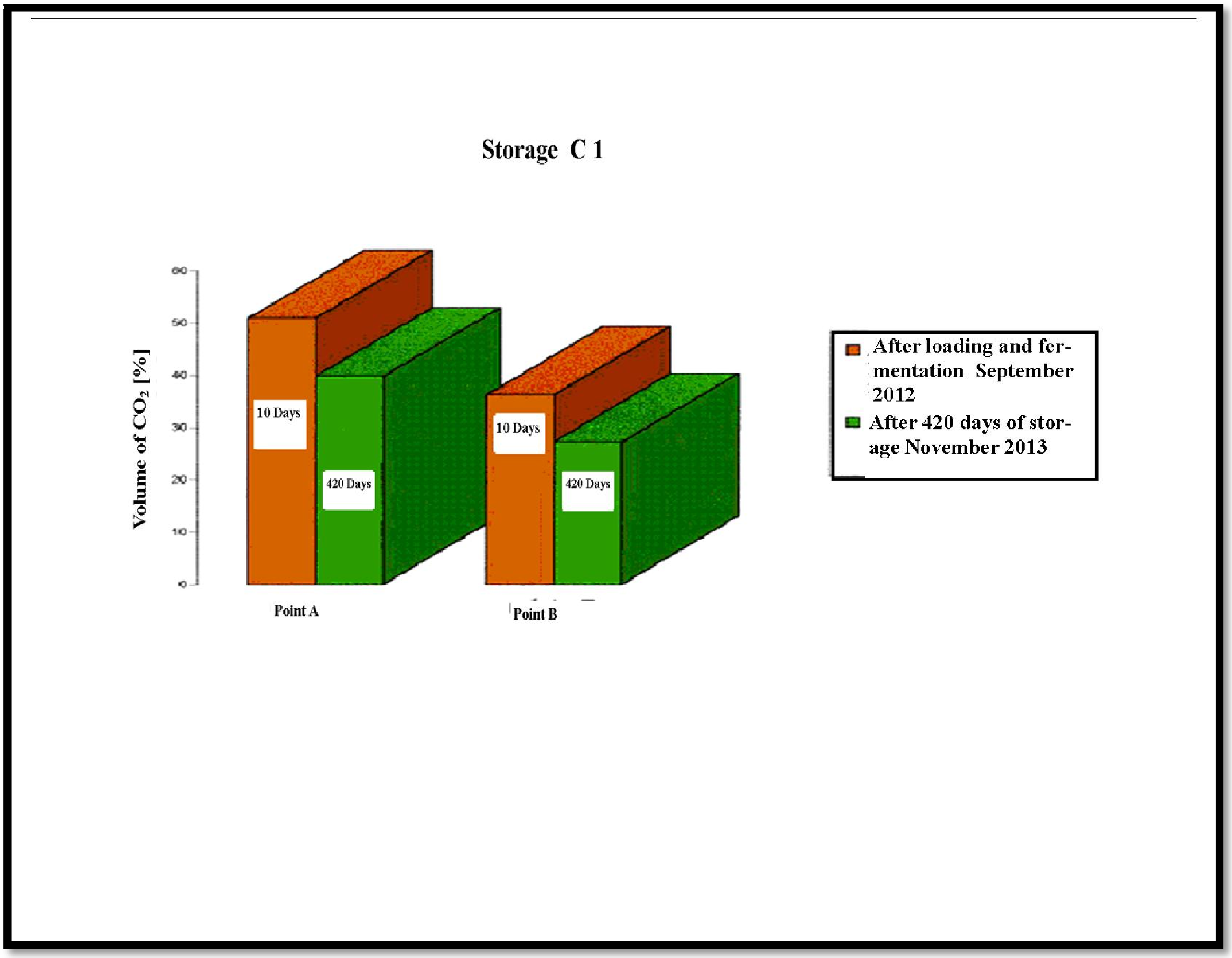
The results shown in the table document that even after a very long storage time, it is possible to maintain the perfect tightness of the stack very high concentrations of CO2.

Table 9 The tightness of containers and the CO_2 content during storage

Tray number	Commodity	Storage time in days	The content of CO2 in the reservoir in%	
			down	above
1	field pea	420	39,8	27,2
4	Feed wheat	420	40,6	28,2
2	corn 23 %	60	31,8	28,6
3	corn 35 %		58,8	56,9

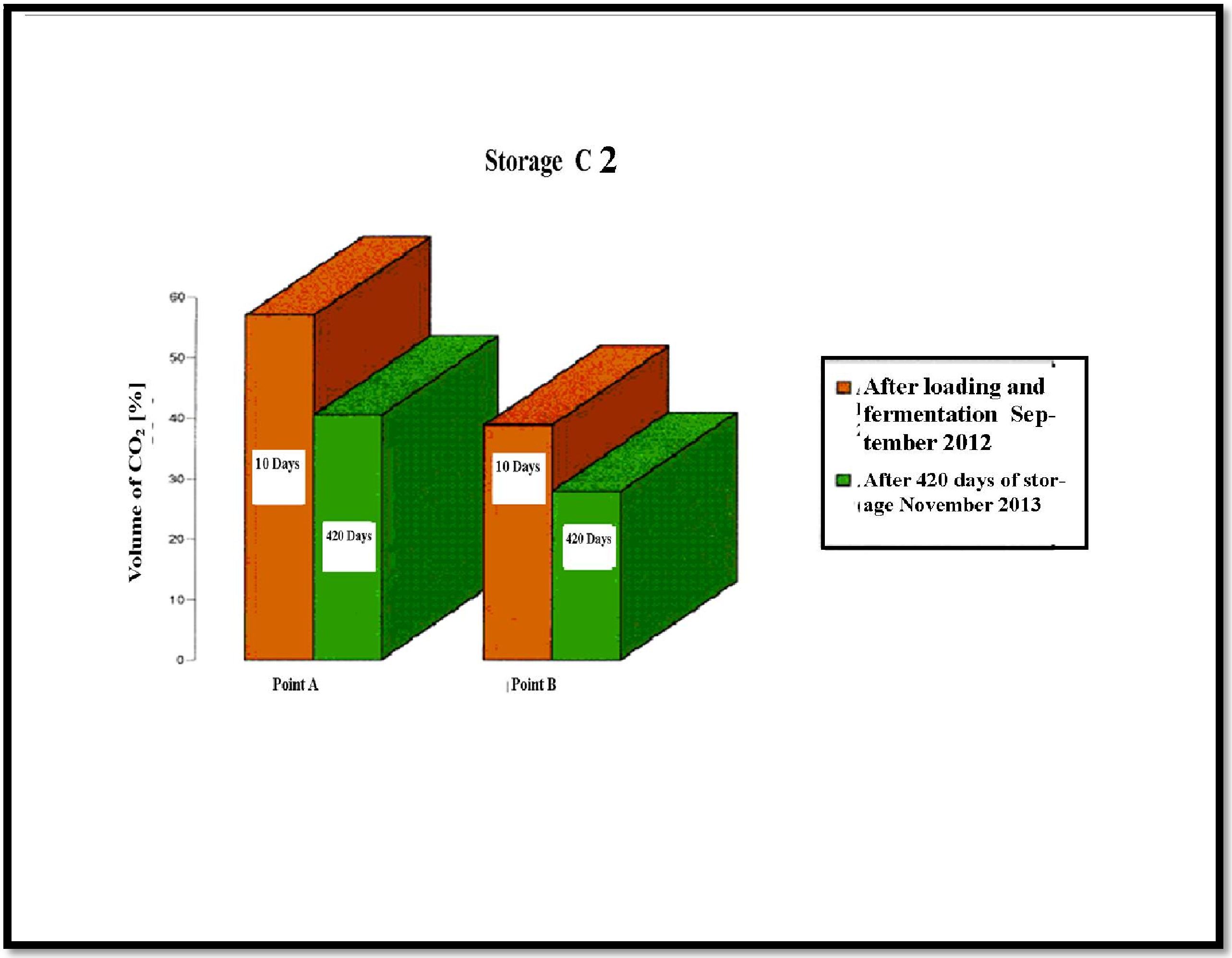
Source: Habimana (2013)

Figure 16 Decrease in CO_2 content during storage



Source: Habimana (2013)

Figure 17 The rate of CO_2 **Atmosphere**



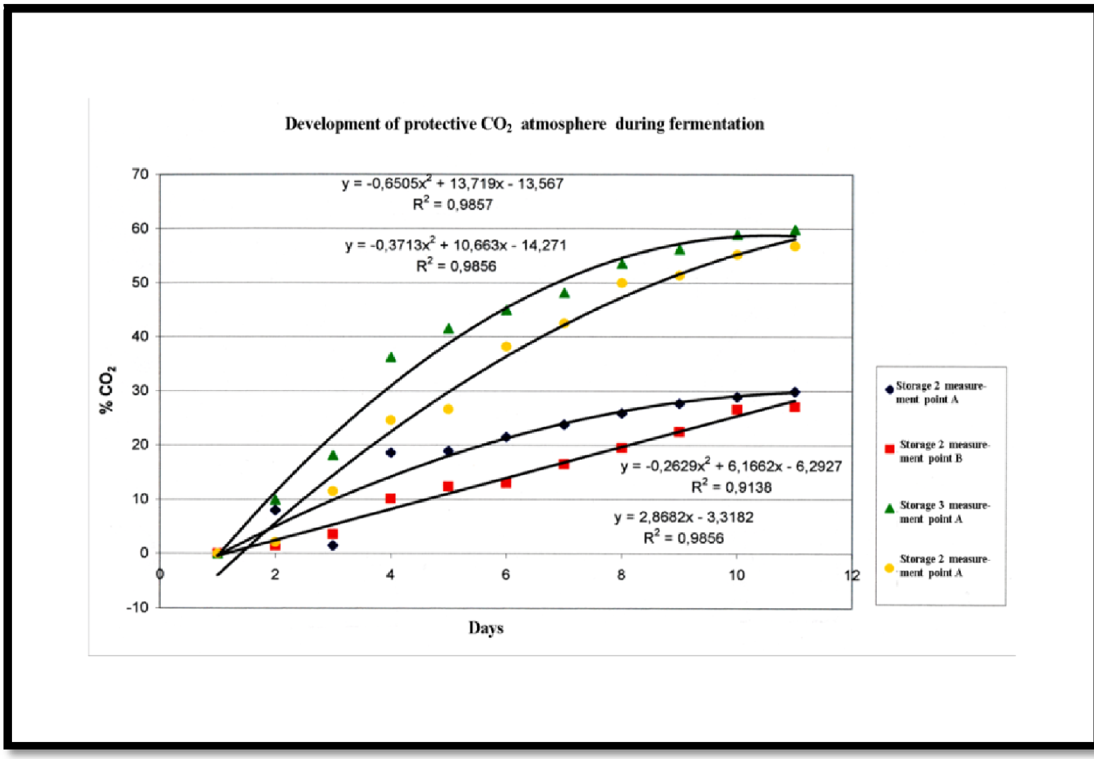
Source: Habimana (2013)

The rate of CO2 protective atmosphere depends on the rate of fermentation.

The decisive for the quality of materials are considered first two days when the onset of the fermentation is usually very fast and after filling, the container must be immediately closed.

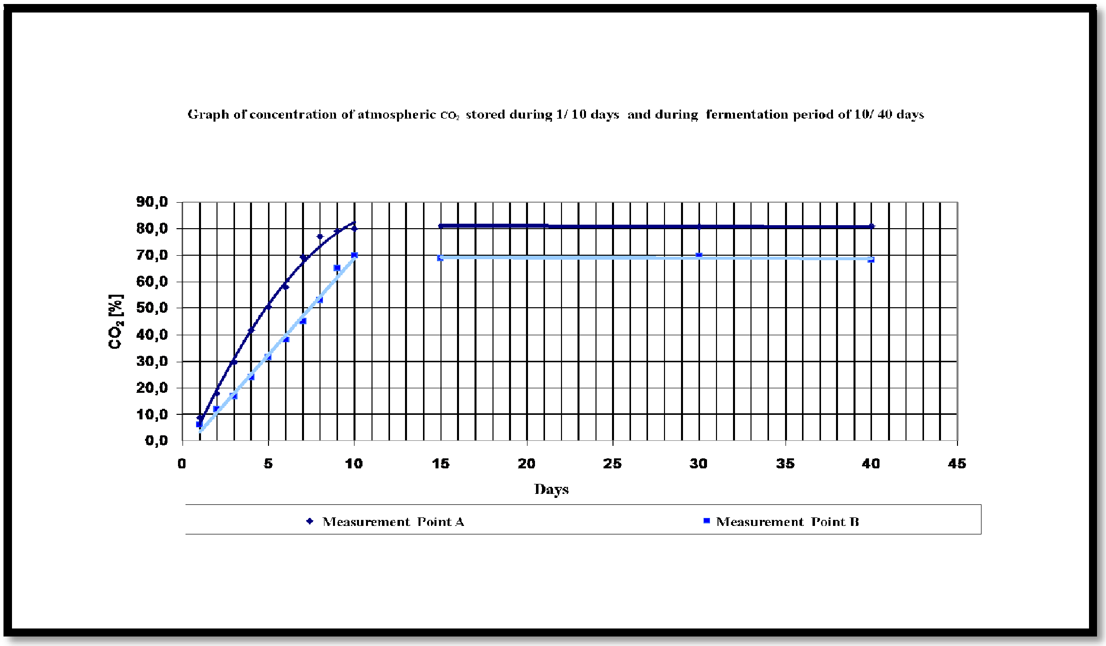
The above chart shows that the fermentation was carried out during 10 days, and during the next days unchanged

Figure 18 Development of CO2 Atmosphere during fermentation



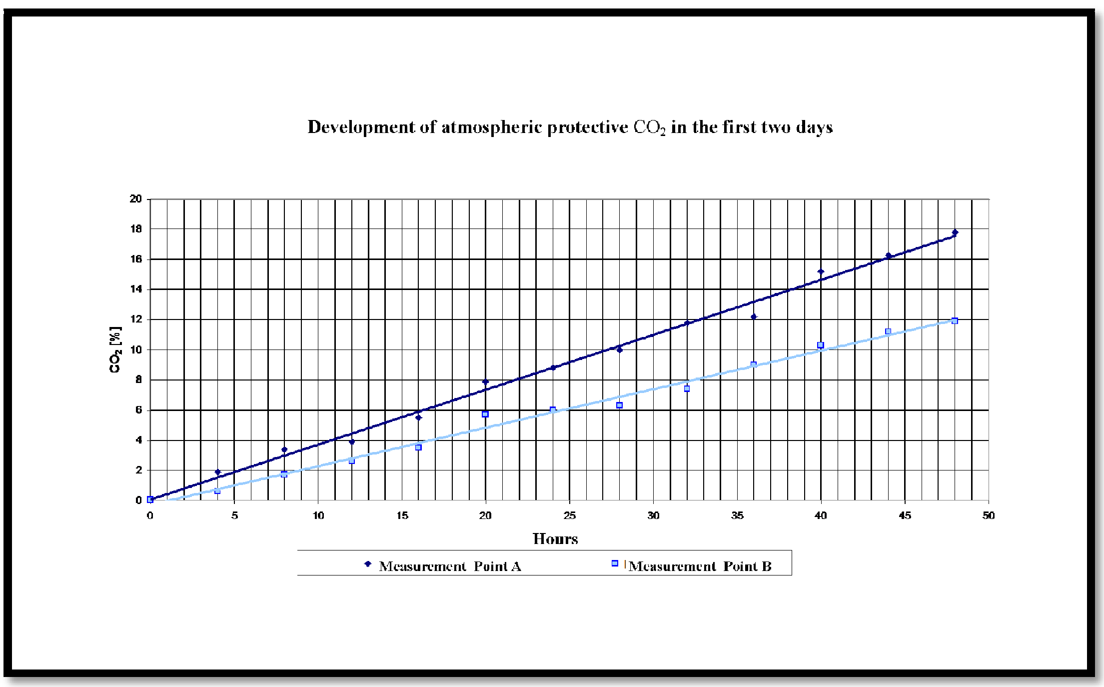
Source: Habimana (2013)

Figure 19 Concentration of CO_2 Atmospheric during storing and fermentation period



Source: Habimana (2013)

Figure 20 Development of CO_2 Atmosphere in the first 2 days



Source: Habimana (2013)

- **Effect of carbon dioxide concentration on the quality of the stored material**

*The aim was to compare the possible effect of CO_2 on a range of undesirable substances***.**

The results indicate that neither reduction in the concentration does not affect the quantity and spectrum mycoflora. It was more of saprophytic species that are not usually producers of mycotoxins.

The table shows the spectrum detected in relation to the concentration of CO_2.

Table 10 Observed mycoflora% in the high and reduced concentration of carbon dioxide

The concentration of CO2	
high	reduced
Penicillinum Sp – 5 %	Aspergillus Sp.div – 5 %
Alternaria Sp – 5 %	Cladosporium – 10 %
	Fusarium oxysp. – 5 %
	Penicillium Sp. – 5 %

Source: Habimana (2013)

6 CONCLUSION AND RECOMMENDATIONS

6.1. CONCLUSION

The climatic conditions in Rwanda do pose a challenge for maize storage. Despite maize being a staple food in Rwanda with high involvement in commerce, literature is either scarce or nonexistent on Techniques used during maize storage. This major finding led to this research on suggestion regulating for post-harvest operations: new trends in maize storage techniques in Rwanda. The grain maize sampling has been made from the Rwanda National Strategic Grain Reserve, and taken to Czech Republic.

The researcher went on an inspection into the Rwanda National Strategic Grain Reserve(NSR), an institution working under the Ministry of Agriculture in Rwanda; and which addresses post-harvest inefficiencies by improving storage facilities and post-harvest practices.

The study was based on chosen maize storage techniques in Rwanda in comparison to the modern techniques of grain storage in CO_2 atmosphere taken as case study conditions. The maize samples properties studied included water activity moisture content, dry matter, ash, crude protein, ether extract, crude fiber, organic matter, iodine number, and nitrogen free extract.

The control of 2012 Season samples, shows an increased to higher water activity values than for the control samples. This interference has been explained by the used technology of hermetically cereals storage in silos in tropic countries; without effective control of development of moisture content for commodities. In tropical climates, even if the commodity stored in metal or concrete silos is sufficiently dry, it suffers from two major problems if stored within metal or concrete silos:

1. Condensation occurring below the roof of the silos and at the top layers of the grain bulk, leading to fungal and insect growth.

2. Contamination with fumigants and chemical contact insecticides necessarily used to prevent insect infestation

According to the performed measurements, testing and verification for the grain storage in CO_2 controlled atmosphere, this technique has shown to be effective , because the corn grain harvested at higher moisture content (up to 35 %) can be stored in a very good quality one year or longer in compliance with the rules stored in a grain storage in CO_2 controlled atmosphere. Maize and other materials may also be retained at a reduced concentration of carbon dioxide , but again with the provision that the concentration will be reduced in the entire profile of the container.

6.2 Recommendations

The Technology of grain storage in CO_2 controlled atmosphere can be recommended to maize storage techniques in Africa, especially in Rwanda. Some on-farm trials in operational have been learned and can be summarized as follows:

- The decisive condition for storage of maize grain storage in CO_2 controlled atmosphere is absolutely hermetic storage space - tower trays.
- The concentration of carbon dioxide must be sufficient in its profile stack , ie . That, on the top level (level " A") stored material must be sufficient concentration of CO_2 . According to our findings for reliable contorol of stored maize is necessary that the atmosphere CO_2 was at least one meter above this level , which reliably exclude the possibility of contamination with oxygen O_2 and the eventual development of mold, fungus and other mycotoxins .
- An important condition is the speed of filling and sealing the container , because the fermentation begins to take place after two hours from the initiation of the tray
- Corn grain harvested at a moisture content up to 35 % , feed grains with higher moisture content 15-20 % (feed wheat) and other commodities for the production of compound feed may be stored in a very good quality one year or longer if stored in a protective atmosphere of carbon dioxide.
- Verification and leak hermeticity tower trays had very little decrease in concentration during 1 year of storage. In both reservoirs was up 12.6 % CO_2 .
- The concentration of CO_2 in corn with moisture content adjusted to 23% is significantly slower in quantitative comparison roughly half.
- Removal from storage of maize and other grains must be processed in a short period immediately . Longer storage leads to the rapid development of undesired mycoflora (according to our analyzes up to 50 % in 48 hours).

7 REFFERENCES

AUC (African Union Commission), 2006. Resolution of the Abuja Food Security Summit. Addis Ababa, Ethiopia.

CIMMYT and IITA, 2010. MAIZE – Global alliance for improving food security and the livelihoods of he resource-poor in the developing world. Draft proposal submitted by CIMMYT and IITA to the CGIAR Consortium Board. El Batan, Mexico. 91 pp.

Egunjobi OA (1974) Nematodes and maize growth in Nigeria. II. Effects of some amendments on populations of *Pratylenchusbrachyurus*and on the growth and production of maize (*Zea mays*) in Nigeria. NematolMedit 3:5–73

FAO Statistics. Website: http://www.faostat.fao.org.

FAO (Food and Agriculture Organization of the United Nations), Agricultural engineering in development: selection of mechanisation inputs, Agricultural Services Bulletin No. 84 (FAO), 1990.

J.F. CRUZ et A. DIOP, Agricultural Engineering in Development: Warehouse Technique, FAO Agricultural Services Bulletin No. 74, 1989.

Ismail AE (2009) Impact of winter wheat, barley, broad bean and clover as preceding crops on population densities of corn cyst nematode, *Heteroderazeae*on corn in Egypt. In: Riley IT, Nicol JM, Dababat AA (eds) Cereal cyst nematodes: status, research and outlook. CIMMYT, Ankara, pp 237–241

Labuza, T. P., & Hyman, C. R. (1998). Moisture migration and control in multi-domain foods. *Trends in Food Science and Technology*, 9, 47–55.

Labuza, T.P. and R. Contreras-Medellin. (1981). Prediction of moisture protection requirements for foods. Cereal Foods World. 26(7):335-343.

Rahman, S. (1995). Food properties handbook. Florida. CRC Press, Inc.

Samapundo, S., Devlieghere, F., De Meulenaer B., Atukwase, A., Lamboni, Y., & Debevere, J. M. (2007). Sorption
isotherms and isosteric heats of sorption of whole yellow dent corn. *Journal of Food Engineering, 79,* 168-175.

Shukla, R., & Cheryan, M. (2001). Zein: the industrial protein from corn. *Industrial Crops and Products 13,* 171–192.

Abbreviations

FAO: Food and Agriculture Organization of the United Nations

MC: Moisture content

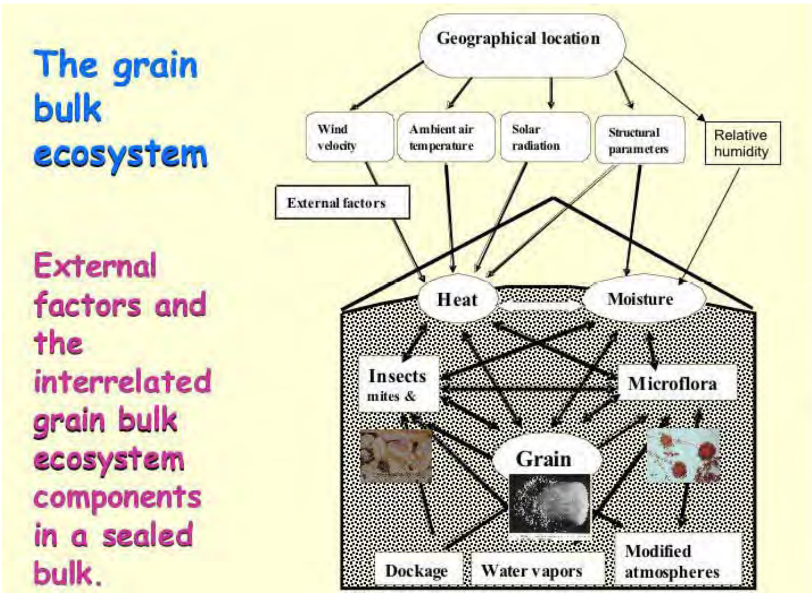
MINAGRI: Ministry of Agriculture

NSR: National Strategic Grain Reserve of Rwanda

RH: Relative Humidity

APPENDIX

Figure A Effect of external factors on a grain bulk storage system



Source: Oduor et al., (2000)

Figure B Maize storage silos in the Rwanda National Grain Reserve

Source: Habimana (2013)

Figure C Maize storage in warehouse in Rwanda

Source: Habimana (2013)

Figure D Screw conveyor and valve for the grain storage in controlled CO2 Atmosphere

Source: Habimana (2013)