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HYBRID DRYER (SOLAR AND BIOMASS FURNACE) TO ADDRESS THE PROBLEM OF POST HARVEST LOSSES OF TOMATOES IN RWANDA

A Research Project submitted to Larenstein University of Applied Sciences In partial Fulfillment of the Requirements for the Degree of Master in Agricultural Chain Management, specialization Post Harvest Technology and Logistics

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DEDICATION

This work is dedicated to my children Agahozo and Mpore who in their tender age showed performance in their studies despite doing without a loving mother. My prayers are with you.

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

List of Figures

List of Tables

LIST OF ABBREVIATIONS

CITT: Centre for Innovation and Technology Transfer

CODECOMA: Cooperation de Development de la Commune Masango

GDP: Gross Domestic Product

KIST: Kigali Institute of Science and Technology

ISAR: Institut des Sciences Agronomiques du Rwanda

MINAGRI: Ministry of Agriculture and Animal Resources

RBS: Rwanda Bureau of standards

REMA: Rwanda Environment Management Authority

RHODA: Rwanda Horticulture Development Authority

RIEPA: Rwanda Investment and Export Promotion Agency

SORWATOM: Societé Rwandaise des Tomates

UNIDO: United Nations Industrial Development Organization

ABSTRACT

Tomato (Lycopersicon esculentum) is one of the important vegetables in Rwandese diet, since it is rich in health valued food components such as carotenoids (Lycopene), ascorbic acid (Vitamin C), vitamin E, folate and dietary fibers. The post harvest loss in tomatoes has been estimated to be about 20-30% at farmer level due to inadequate post harvest handling, lack of infrastructure, processing technologies, marketing and storage facilities.

"SORWATOM -" a tomato processing plant located in Kigali has poor linkages with tomatoes farmers resulting in unreliability of supply in terms of quantity and quality and this translates into high postharvest losses to the farmers.

Though sun drying has been used in Rwanda for drying agricultural products for reducing moisture content and extending shelf life, it is a slow process and the quality of the dried product is often inferior due to contaminations. Therefore a cabinet hybrid dryer, using solar energy and biomass furnace was tried to increase the shelf life of tomatoes and to minimize these losses.

During drying, it was observed that the temperature inside the solar hybrid cabinet dryer was 70 ºC when the maximum ambient temperature was only 27 ºC. The tomato slices of between 6 and 8 mm thicknesses were dried from 94 to 9 % moisture content for an average time of 12 hours. The weight and volume of tomatoes was decreased by 92 %.

It was found that the drying process could allow the extension of the shelf life of tomatoes by reducing the moisture content and thus the product weight and volume, and was a relatively low cost and simple technology that could be addressed to the crucial problem of post-harvest losses in tomato in Rwanda. Drying produce in harvest seasons where the prices are low and selling in off-seasons where prices are high can be a good opportunity for tomatoes farmers to improve their income.

Therefore this technology almost unknown in Rwanda was strongly recommended as one of the most promising alternatives to reduce post harvest losses.

Key words : Tomatoes, post harvest losses, drying technology ,hybrid dryer

1. INTRODUCTION

1.1Background

Rwanda is located on the limit between central Africa and the East Africa .It has a total area of 26,338 km2 with 24,948 km2 of land and 1,390 km2 for water . Its land is typically hilly with swamps between extensive mountainous areas. The countries bordering are: Uganda (in North), Tanzania (in the East), Burundi (in the south) and the Democratic Republic of Congo (DRC) in the West.

Rwanda is known for the genocide in 1994 that was carried out by the ethnic extremists who left nearly one million people dead and 3millions fled into exile in neighboring countries (MINECOFIN 2002)

The government was in a state of collapse, and the economy and physical infrastructure were destroyed. Shelter and capital stock were reduced at a great deal both in the household and small business sector. Networks of social links, in rural and urban areas, have been damaged, impeding internal commerce.

The war and genocide left 85,000 child-headed households. Some of the children have since grown up or been absorbed into household, but most of them still face a higher burden of responsibility and work than their peers. A high proportion of household are headed by women (34% in 1996) and by female widows (21% in 1996). Men form the minority of the adult population. While the widow-headed households are often amongst the poorer households, the high proportion of female household heads has also presented a challenge to the traditional gender roles in Rwanda. The prevalence of HIV has increased dramatically. The prevalence is 11.1% nationally and 10.8% in rural areas, compared to a rate of 1.4% in rural area in 1987 (MINECOFIN 2003). However, because of the war and the widespread poverty there has developed a vulnerable population (orphans, child headed household, widows, victims of systematic rape during the war, refugee situation, ect) which gives reason to believe that the current projections estimate the prevalence rate to be 13.5%. This made that the working population in rural areas is strongly decreasing.

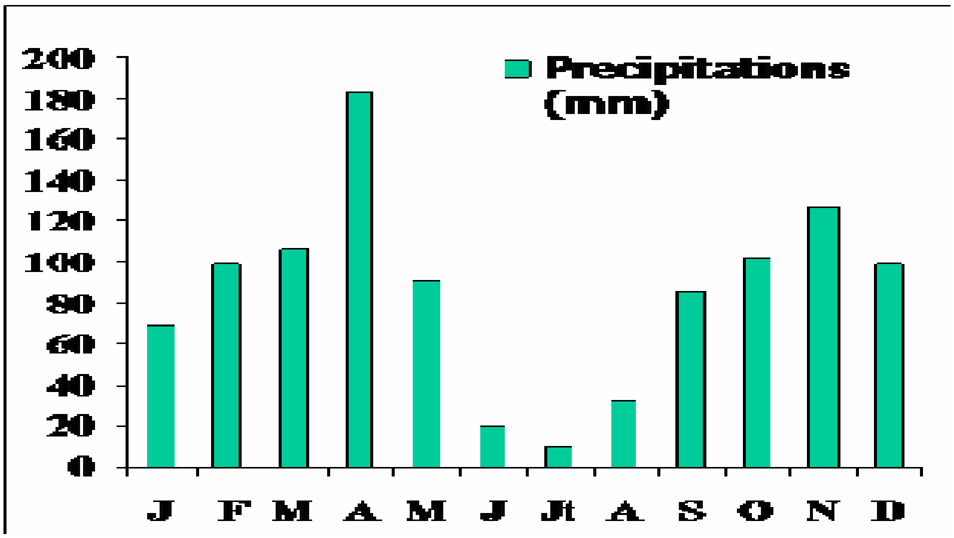
Since the end of the genocide, the Country has embarked on a process of national reconciliation and rehabilitation of social welfare, which is essential to reconstruction. The national process of reconciliation was centered on: the arrest and trials of the presumed authors of the genocide; the implementation of the process of popular trials and reconciliation under the Gacaca judicial system. This involves reinsertion of the people displaced inside and outside the Country. Similarly, it gets down to restoring social links between urban and rural areas for social cohesion and the functioning of agricultural trade.

Now, almost 14 years after the genocide, Rwanda has reached to the level of economic development above that existed in 1990, before the war began . Because the Government of Rwanda gives priority to safety and security, an environment conducive to economic and social development was maintained within Rwanda. Decentralized political and administrative structures, which encourage the population’s participation, have been set up.

Rwanda is land-locked and dependent on air or overland road transport. The economy of Rwanda is mainly agricultural. In 2002, the agriculture sector accounted for 43% of GDP and sustains almost 90% of the population. The agricultural use depends almost exclusively on the quality of the rainy season, which makes the country particularly vulnerable to the climate change.

Average annual rainfall in the whole of Rwanda is 1111mm, but there are some variations from 700 mm in the North-West to 1600 mm/year in the South-West.

Figure 1: ***Average annual rainfall in Rwanda***

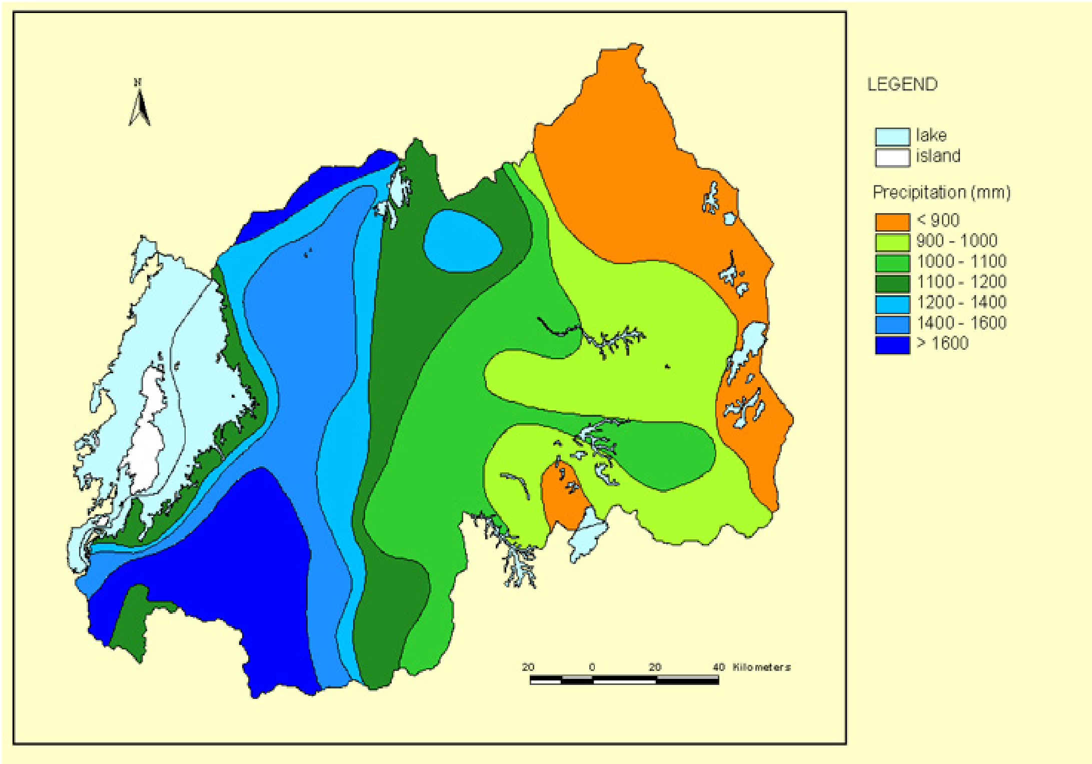


Source (MINAGRI 2006)

Rainfall changes according to altitude. Rwanda is subdivided into three altitude areas: (i) the area of low altitude under which covers the whole East of Rwanda. (ii) the area of medium altitude between 1500 m and 1900 m stretching on the both sides of the Congo-Nile Ridge's lands. (iii) The area of high altitude above 1900 m and including the Congo-Nile Ridge's high lands and the volcanic high lands Three areas are distinguished; 1500 mm/year in the South-West and in the North-West, intermediate area between 1000 and 1500 mm/year in the West of the country and 1000 mm/year low rainfall area in the East. The climate in Rwanda is favorable to crops production, with a dynamics of two rainy seasons alternating with two dry seasons:

Short rainy season from Sept till Nov
Long rainy season from February till May
Short dry season from Dec till January
Long dry season from June till Sept

Figure 2*: Rainfall distribution in Rwanda*



Source(MINAGRI 2006)

Agricultural production is characterized by: Subsistence farming, small farm holdings (0.7 ha per household or 0.14 ha per person), weak agricultural research, very low levels of investment in the agricultural sector.

The agriculture policy in Rwanda aims to transform this subsistence agriculture into the market oriented one. A strategic plan for agricultural transformation have been set up, with four key priority and interrelated programs: intensification and development of sustainable production systems support to professionalization of the producers, institutional development and promotion of commodity chains and development of agribusiness.

Vegetables and fruits possess a tremendous potential to contribute not only to the country's nutritional needs, but also adding to the national export earnings. Vegetables and fruits are mostly produced in the south province, which alone accounts for 60% of the total produce in the country. Other provinces bearing a fair share in market gardening include Kigali Capital City peripheral zones (17%), Northern Province (13%) and Western province (11%)

(KANYARUKIGA 2005)

The main vegetables grown in Rwanda are Tomatoes, Cabbages, Carrots, Onions, and Peppers, Cucumbers .The majority of vegetables producers are small scale farmers producing and selling their products without any market contract.

Table 1*: Production areas and markets of vegetables in Rwanda*

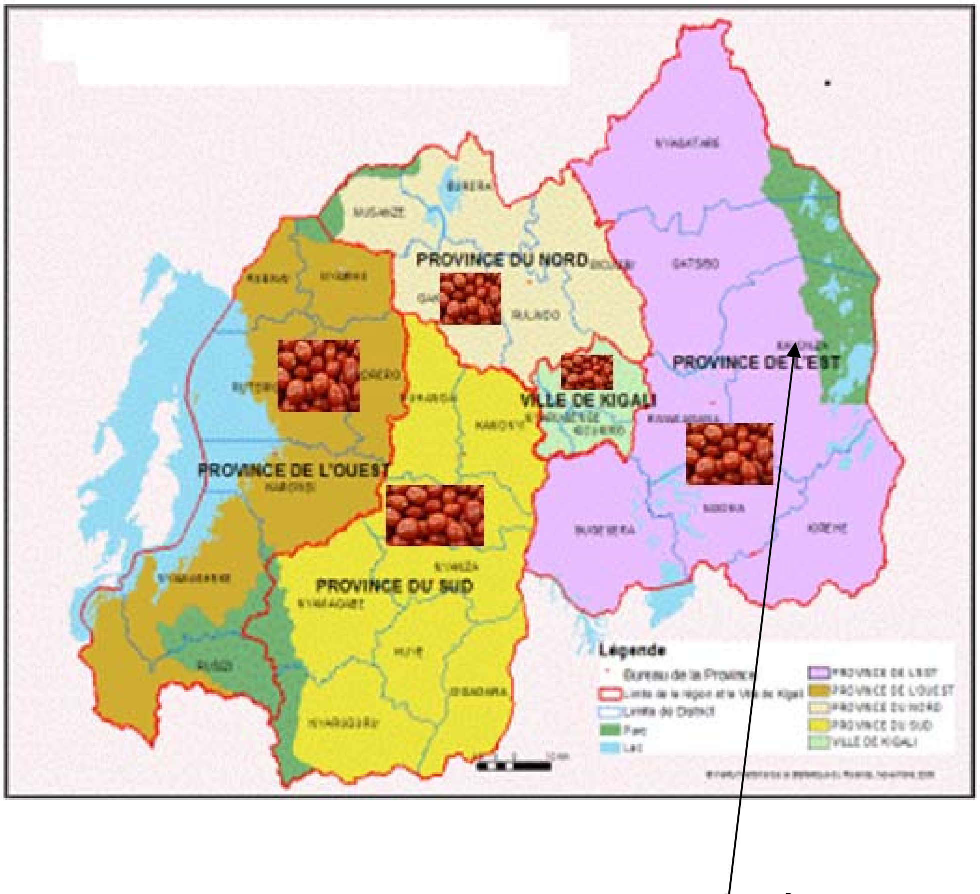
Provinces	Soil description	Vegetable commodities	Principle market

Western Province	Marshland soils of Bugarama(Cyangugu)	Tomatoes	Town city of Cyangugu(Rwanda) Bukavu Town city (Republic democratic of congo)
	Volcanic soil of Gisenyi (very fertile)	Carrots Onions	Gisenyi Town city Musanze Town city Kigali Capital City
Northern Province	Musanze Volcanic soils	Carrots, Onions	Ruhengeri Town City
	Musanze peripheral marshlands	Tomatoes	Ruhengeri Town City
	Rulindo and Burera marshlands	Cabbages, Peppers, beans, Cucumber	Kigali capital cities
	Mountain soil of Byumba	Carrots	Byumba town city Kigali capital city
Southern Province	Gitarama marshlands	Cabbages, tomatoes, onions	Gitarama town city Kigali capital city
	Butare marshlands	Tomatoes, onions	Butare town city
		Peppers (apsicum)	export
Eastern province	Kigali peripheral zones	tomatoes	Kigali capital city
	Kibungo zone	Tomatoes	Kibungo town city

Source:(KANYARUKIGA 2005)

Records show that Rwanda produced more than 764,000 tones from an area of 30560 ha. These figures are from a survey done by Rwanda Horticulture Development Authority (RHODA) in August, 2008. The known yield per hectare is between 25 and 30 tones. Taking into account the quality of the soil in Rwanda, the tropical climate, the abundant rainfall and the number of swamps available for the growth of fresh tomatoes, the quantity and quality should increase greatly if adequate postharvest handling technologies are set up to encourage agriculturalists.

Figure 3***: Areas of Tomatoes Production in Rwanda***



1.2 Problem statement

Tomato (*Lycopersicon esculentum*) is one of the most widely used vegetables in Rwanda. It is highly a seasonal crop, and hence there is surplus at a particular season of the year, the physiological nature of tomato (high moisture content, high respiration rate, soft texture) subject it to microbiological, mechanical, physiological damages. In addition to that there is poor or absent post harvest handling facilities in rural area. All these factors lead to high post harvest losses. Therefore, it is essential to preserve the tomatoes by using any of the food preservation techniques and to be made available in an acceptable form throughout the year at relatively minimum cost. As such, tomatoes can be dried by hybrid solar dryer in order to save the part of the production that will not be readily consumed, since drying is a classical method of food preservation, which provides an extension of shelf-life, lighter weight for transportation and less space for storage.

Therefore hybrid solar drying technology offers a big challenge for minimizing these losses at low cost.

1.3 Justification of the study

Post-harvest food losses can exceed 30 per cent and even reach 50 per cent of total food production, depending on the type of products and the storage conditions. Storage losses therefore contribute considerably to the reduction of available foodstuffs. Post harvest losses from producer to the consumer may be as high as 50% in fresh vegetables in Rwanda(Watkins and Anubha 2007).Postharvest losses, which decrease returns of farmers, occur mainly because of the lack of infrastructure and/or poor handling and processing technologies and marketing know-how. Tomatoes are short duration crop, giving high yield. But the excess production results in a glut in the market and reduction in tomato prices. Also, it is highly perishable in the fresh state leading to wastage and losses during the peak harvesting period. The prevention of these losses and wastage is very much important especially due to subsequent imbalance in supply and demand at the harvesting and off season and economic consideration (Karim and Hawlader 2005). Therefore, there is a need to increase the shelf life of tomatoes either in fresh or in processed form using food preservation techniques. The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time, normally regarded as the “safe storage period” (Rajkumar, Kulanthaisami et al. 2006).

The drying of fruit and vegetables is a subject of great importance. Dried fruit and vegetables have gained commercial importance and their growth on a commercial scale has become an important sector of agricultural industry (Karim and Hawlader 2005).

1.4 Objective of the research

To assess the effectiveness of hybrid dryer (solar and biomass furnace) in addressing the problem of post harvest losses of fresh tomatoes in Rwanda.

1.5 Main Research questions/ guiding questions

Q1. What are the causes of post harvest losses of fresh tomatoes in Rwanda?

Sub questions

What are the physiological characteristics of fresh tomatoes?
What are the deteriorating agents of fresh tomatoes?
What are the post harvest handling conditions of fresh tomatoes?

Q2. What are the main problems faced by farmers for handling fresh tomatoes in Rwanda?

Sub questions

How are they storing their fresh tomatoes?
How is the transport of fresh tomatoes?
How is the market when production season?

Q3. How can Hybrid drying minimize post harvest losses of fresh tomatoes?

Sub questions

What is the technology of solar drying?
What is the effect of solar drying to physiological characteristics of fresh tomatoes?
How solar drying increase shelf life of tomatoes?
How solar drying affect the storage of tomatoes?
How solar drying affect the transport of tomatoes?

1.6 Location of the study area

The area of the research was Kayonza district in eastern province of Rwanda. Kayonza is the one of seven districts of the Eastern Province. Its geographical location, about 90 km away from Kigali gives it logistical problems for selling its fresh tomatoes before being spoilt city. It is composed of hills and slopes whose altitude varies between 1400 m and 1600m.The climate is hot and humid. The average annual temperature varies between 18 and 26 ^{0}c.The averages annual rainfall varies between 1000 mm and 1200 mm, the months of March and April being the wettest. More than 90% of its population depends on subsistence agriculture and livestock keeping for their living. The majority of the population lives in rural villages and the important commercial centres of Kabarondo and Kayonza.

1.7 Limitation of the study

Tomatoes are produced in almost all regions of Rwanda, there is always production peacks and lows in some regions depending on the seasons. It is in the long dry season (July to September) when there is very low supply due to seasonality in production. This coincided with the time of carrying out the research. Most farmers were not in production except few producing tomatoes in swamps area and that limited observation on post harvest practices and post harvest losses. The other bigger problem, till now there is no available information on tomato production and other agricultural products in Rwanda (quantity), any survey was done in this matter.

1.8 Organization of the thesis

This report starts with an introduction to the research background, starting with the research problem, objective as well as describing the study area. The second part analyses the tomato sector and its supply chain with emphasize on post harvest handling practices and post harvest losses. The third section looks at the literature that was reviewed to come with relevant information that supported the research objective and methods of carrying out the research.

Methods of carrying out the research are covered in the fourth section. Results of the research are presented, analyzed and discussed in the fifth part of the report. The report ends with a conclusion and recommendation on minimizing post harvest losses of fresh tomatoes in Rwanda.

2. SECTOR ANALYSIS

2.1 Background

Horticulture is the single largest traded industry in the world, with annual trade generating around $57 billion   Sub-Saharan Africa contributes only 5% to this trade. In East Africa Region, horticulture is Kenya's largest export industry generating more than $ 400 m surpassing even coffee and tea. Ugandan horticulture exports totalled $ 60 m in 2005. Ethiopia has managed to grow a horticulture industry that generates $30m annually in exports in just four years. This industry provides significant advantages to many developing countries around the world.

With regards to this reality, Rwanda, in its Vision 2020 plan, has set ambitious goals for its development. Between 2000 and 2020, the country would like to grow its per capita GDP from $250 to $900, which implies that the overall economy needs to expand by over 600%. Horticulture has been identified as a priority export sector as well as a local market one. According to the Ministry of Agriculture and Animal Resources (KANYARUKIGA 2005), for Rwanda, there are many benefits to be gained from focusing on horticulture. These are mainly expressed through poverty alleviation (employment and farm income), export diversification (break away with traditional export commodities), exports receipts (existence of potential for horticulture to become a sizeable export contributor for Rwanda).

Rwanda is blessed with the natural climatic conditions necessary to win in horticulture: the right soils, temperatures, rainfall, and sunshine, as well as an abundant and hard working labor force. As one Dutch flower investor from Kenya was recently quoted as saying: *"Rwanda is one of the last unexploited corners of Africa with the right conditions for horticulture"(KANYARUKIGA 2005).*

Crop production in Rwanda is often categorized into food crops (potatoes, bananas, cassava, pulses, sorghum as major chief's food crops), industrial crops or cash crops (coffee, tea, and pyrethrum), horticultural crops (flowers, vegetables, and fruits, spices and herbs) and the category of new crops (sericiculture, molinga, aloe vera, etc.).Tomato being a vegetable falls under the Horticultural sub sector. Vegetables and fruits possess a tremendous potential to contribute not only to the country's nutritional needs, but also adding to the national export earnings.

Currently that subsector is in its infancy in Rwanda: in 2005 less than $1 million in receipts were generated from exports. There is currently one flower exporter, and one fruit exporter. Domestically, statistics indicate that fruit and vegetable production (targeted for domestic and regional markets) is around 960,000 tons' and is growing due to yield increases and a doubling in recent years of land under cultivation (KANYARUKIGA 2005).Because the government recognize the potential role that horticulture industry could play in the country's economy, Rwanda Horticultural Development Authority was established to promote and develop production and marketing of horticultural produce.

The horticulture sub sector had been seen as viable solution for Rwanda's needs for cash crop diversification, enhanced food nutrition, income generation, employment creation and foreign exchange earning in addition to providing raw material for the agro processing industries.

2.2 The tomato sector and its supply chain

2.2.1 Introduction

Tomato (*Lycopersicon esculentum L.var*) is one the most important vegetable grown in a Rwanda, mostly in open field. It is a commercially important crop both for fresh vegetable market and for the food processing industries. Rwanda produces tomato in almost its regions .Two types of tomatoes are grown in Rwanda, the soft one, Beefsteak in the way of disappearing and the ROMA variety.

The ROMA variety is the dominant one distributed by Ministry of Agriculture and Animal Resources .It is popular and preferred by farmers due to its high resistant to post harvest damages. The seasons of tomato production vary from one to four times in a year.

With regards to the general considerations related to actual land size situation, farming objectives and the marshlands status and accessibility, Rwandese tomato farmers can be categorized into three main groups.

The first category includes individual farmers who perform the tomato farming at a garden scale. The second category includes individual farmers who produce tomatoes for market. Their production is sold as raw material at local market or at farm gate without any market contract. The third category gathers those individual farmers as well as organized ones who perform production activities and sell their produce to SORWATOM (Societé Rwandaise des Tomates) factory with a pre-signed contract and that factory transform fresh tomatoes in tomato paste. The individual land size varies from 0.2 to 5 hectares. Concentrating on the market forces in tomato, it has been to be said that the natural occurrences such as the composition of the soils, the weather are mainly responsible for creating opportunities and constraints on the supply side from different regions of the country. Seasonality strongly influences the supply side of the tomatoes. Furthermore the importance of the chain coordination and chain participation has been highlighted and described as one of the most important constraints responsible for the poor performance of the African agricultural sector(Koenig, Blatt et al. 2008),this is applicable to tomato sector in Rwanda.

2.2.2 Cost of production

The tomato production takes three to four months and during that time an intensive labor is required since any deficiency in pre-harvesting activities results to partial or total loss of tomato quality and quantity. The cost of production varies according to the category of farmer and the season.It varies from 50,000 RWF to more than 200,000 RWF for 0.2 to 5 hectares (850RWF= 1Euro at the time of the research). These figures are at lowest side since the farmer considers only the cost of inputs and the hired labor; the family farm labor is not valued.

2.2.3 Post harvest handling

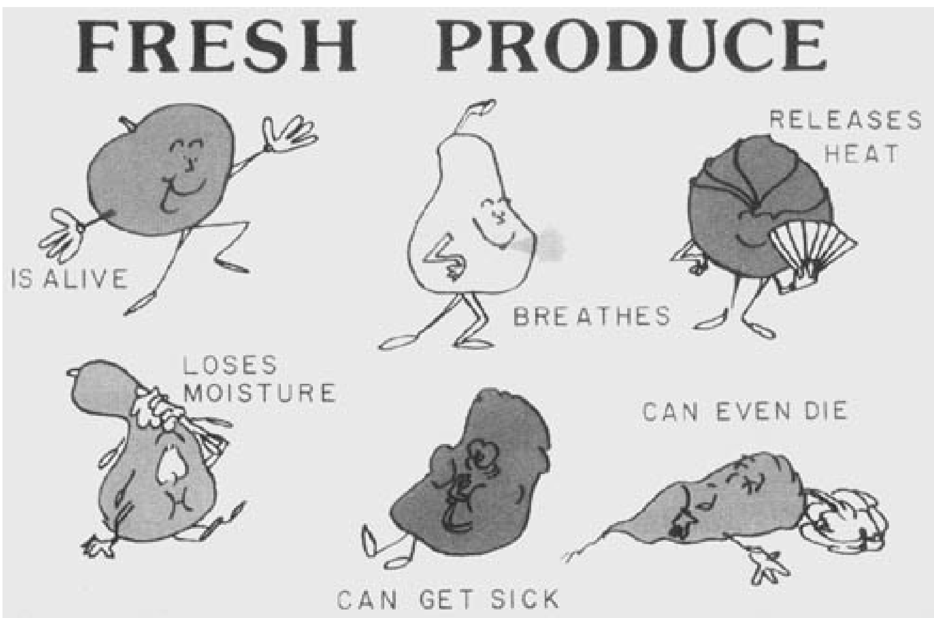
2.2.3.1 Physiological characteristics of tomatoes

High quality ripe tomatoes contain around between 90 and 95 % of water and 5-8 % dry matter .The carbohydrate concentration(mainly as equal amounts of glucose and fructose) increases progressively through maturation and ripening and can account for 50% of the dry matter. Ripe fruits are good source of vitamins A and C and Potassium. Fruits color is probably the most important attribute that determines overall quality and is associated with the loss of chlorophyll and the accumulation of Lycopene.

2.2.3.2 Physiological disorders

A number of disorders affect the quality of fresh market tomatoes. These disorders result from a combination of environment, production and handling procedures or are genetic in origin(Genova, Weinberger et al. 2006).Due to physiological nature (high water content, softness..),fresh tomatoes are subjected to microbiological instability and deteriorative chemical reactions. These disorders decrease the quality and quantity of fresh tomatoes leading to enormous post harvest losses (see figure 4).

Figure 4*: Physiological characteristics of a fresh tomato*



Source:(Acedo and Weinberger 2006)

The loss of tomato quality is generally caused by:

Growing conditions: Lycopene (red color) in tomatoes is restricted under high temperature conditions. As a result, the fruits develop light red or yellowish red color since B-carotene formation is favored instead.

Metabolic stress or natural senescence: Tomatoes are damaged if stored below 12oC because of the development of chilling injury. Natural senescence also causes a loss of quality and may involve loss of color, softening and development of rots.

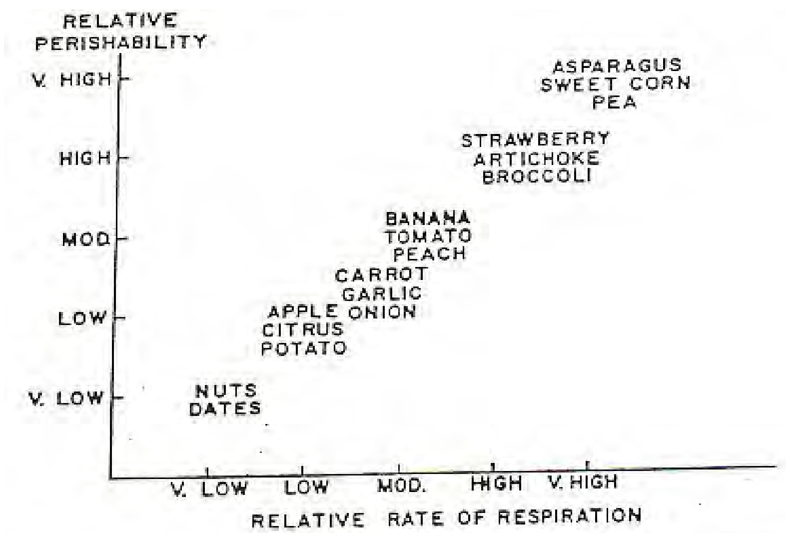
Transpiration and water loss: Water loss causes tomatoes to lose their “freshness”. Produce displayed in supermarkets is often exposed to dry air for long periods and this causes a loss of quality.

Mechanical injury: Faulty handling causes mechanical injury such as bruise, cuts or cracks. Care must be taken along all steps in the chain to reduce product losses as a result of physical damage.

Infection by microorganisms: Microorganisms cause rots and these make the product unsalable. Latent fungi are on the skin of the fruit at harvest and when the conditions are right after harvest these pathogens can quickly grow and infect and damage the tomato fruit.

Packaging: Improper packaging can cause a loss of tomato quality as it can produce physical injuries and when there is no ventilation, it can cause decay of these tomatoes.

Figure 5*: The rate of deterioration or perishability of fresh horticultural products in relation to their morphology and respiration rates*



source:(Acedo and Weinberger 2006)

2.2.4 Post harvest losses

“Losses” are changes in the availability, edibility, wholesomeness or quality of the food that prevent its consumption by people.

Despite the development of improved varieties with better resistant quality and shelf life and the improvement of production systems, the tomato industries particularly in developing countries like Rwanda have not significantly advanced because postharvest losses due to fruit over-ripening, decay and physical injuries remain high. As a consequence, farmers income remain low due to low farm gate prices and retail prices remain high as the losses are passed on to farmers and consumers. Several factors contribute to postharvest losses and some of the technological factors include faulty harvesting and handling practices, poor packaging and transport systems, lack of storage facilities and lack of processing techniques. The principal causes of post harvest losses of fresh tomatoes are: bruising, over-ripeness and excessive softening at harvest, water loss, chilling injury, compositional changes and decay(Kitinoja and Kader 2004). Effective management during the postharvest period, rather than the level of sophistication of any given technology, is the key in minimizing post harvest losses.

While large scale operations may benefit from investing in costly handling machinery and high-tech postharvest treatments, often these options are not practical for small-scale handlers. Instead, simple, low cost technologies often can be more appropriate for small volume, limited resource commercial operations, farmers involved in direct marketing, as well as for suppliers to exporters in developing countries.

Many recent innovations in postharvest technology in developed countries have been in response to the desire to avoid the use of costly labor and the desire for cosmetically "perfect" produce. These methods may not be sustainable over the long term, due to socioeconomic, cultural and/or environmental concerns. For example, the use of postharvest pesticides may reduce the incidence of surface defects but can be costly both in terms of money and environmental consequences. In addition, the growing demand for organically produced fruits and vegetables offers new opportunities for small-scale producers and marketers(Kitinoja and Kader 2004).

Local conditions for small-scale handlers may include labor surpluses, lack of credit for investments in postharvest technology, unreliable electric power supply, lack of transport options, storage facilities and/or packaging materials, as well as a host of other constraints. Fortunately, there is a wide range of simple postharvest technologies from which to choose, and many practices have the potential of meeting the special needs of small-scale food handlers and marketers. Many of the practices included in the manual have successfully been used to reduce losses and maintain produce quality of horticultural crops in various parts of the world for many years (Kitinoja and Kader 2004).

There are many interacting steps involved in any postharvest system. Produce is often handled by many different people, transported and stored repeatedly between harvest and consumption. While particular practices and the sequence of operations will vary for each crop, there is a general series of steps in postharvest handling systems that will be followed for the purposes of reducing losses.

Harvesting and Field Handling

Four major factors are considered during and right after harvest of tomatoes, namely; harvest maturity, time of harvesting, method of harvest, and handling of harvested fruits in the field (or field handling).

Harvest maturity

Tomatoes can be harvested at maturity stage depending on the purpose for which they are grown, distance from production area to consumption area.

For distant markets or if longer storage period is desired after harvest, tomatoes are harvested mature-green or less ripe (e.g. breaker stage). Being a climacteric fruit, tomatoes harvested green but fully mature can ripen normally and can develop optimum quality. In contrast, immature fruits will fail to develop full color and flavor and will deteriorate easily after harvest (Acedo and Weinberger 2006).

For nearby markets, tomatoes can be harvested at the breaker, pink or firm-ripe stage.

Time of harvesting

Harvesting is done at cooler times of the day preferably early in the morning, taking advantage of the lower temperature which minimizes fruit heat load and increases work efficiency of harvesters. Harvesting starts when morning dew has evaporated to avoid damage to the plants due to turgidity, otherwise or if harvesting has to be done very early in the morning, care must be observed to avoid damage to the plants that still have fruits for subsequent harvesting.

It is not advisable to harvest when it is about to rain or just after a rain because disease incidence could be higher (Acedo and Weinberger 2006). Rain water can accumulate on the stem end of the fruit which is the main entry point of decay-causing microorganisms and could create a favorable condition for microbial growth. However, if harvesting cannot be avoided during rainy days, the fruits must be washed and dried properly before packaging. Washing and drying become doubly necessary for fruits from plants not staked or trellised since soil particles, which may contain decay organisms, could adhere to the fruit especially during rainy season.

Method of harvesting

Hand-picking is the usual method of harvesting. Pulling the fruits from the plant should be avoided as it could damage the plant for subsequent harvesting and may unnecessarily result to the removal of the fruit pedicel, exposing the fruit stem-end which is the main avenue for gas exchange (i.e. exit of water vapor thereby increasing loss of water and weight; entry of oxygen and exit of carbon dioxide thereby increasing the rate of respiration and other metabolic activities). Other necessary care during harvesting should be observed to avoid or minimize physical injuries such as wounds inflicted by the finger nails of harvesters. Harvesting containers, preferably made of plastic because of their smooth surfaces (e.g. small plastic pails or trays), are recommended. This will facilitate collection with minimal or no damage to the fruits.

Field handling

Dropping fruits to the harvesting container or when transferring them into the collecting or hauling container should be avoided.

Otherwise, impact bruises can result to non-visible symptoms of deterioration such as browning or blackening in the seed area. Bigger containers are used to facilitate handling and bringing the produce from farm to the packinghouse. Plastic crates are recommended but low-cost containers such as bamboo crates can be used. For bamboo baskets or wooden crates, liners such as fresh banana leaves or old newspapers should be used to protect the fruits from the sharp surfaces of the container.

Other faulty practices during field handling include throwing of fruits to container, dropping and dragging of containers during hauling. These practices can result in both visible and non-visible physical injuries. Visible injuries can be in the form of cuts, punctures or abrasions. Aside from their adverse effect on visual quality, physical injuries hasten water loss and ripening and serve as entry points of microorganisms.

Harvested tomatoes are temporarily kept under a shaded area to avoid exposure to the sun that may result to sunscald, rapid water loss leading to wrinkling, and accumulation of field heat that accelerates ripening(see figures 6 and 8). A rise in fruit temperature occurs when the fruits are left exposed for one to two hours. The heat that accumulates inside the fruit is later released and may cause heating inside the packaging container, transport load or storage area.

Fruits harvested at different stages of ripeness can be sorted during the harvesting and field handling operations by either placing them in separate containers or in collecting containers with improvised dividers.

Sorting of fruits according to size and freedom from defects can also be done simultaneously if experienced pickers are employed(Genova, Weinberger et al. 2006).

Packinghouse Operations

The main operation in the packinghouse is packing or packaging prior to storage or transport to markets. However, other operations before packing (prepacking operations) are usually done to minimize losses during transport and storage and obtain the desired quality during marketing and utilization. Prepacking operations for tomatoes may include cleaning and decay prevention, sorting or grading, ripening control treatments, and precooling. Before each of these operations is elaborated, the establishment of simple packinghouses is presented.

Simple packinghouse

A simple roofed structure or shed house can be developed as an area for the different packinghouse operations (Acedo and Weinberger 2006).The minimum requirements are proper flooring and roofing, adequate ventilation, and an area for sorting and packing, applying commodity treatments (e.g washing/drying, ripening treatment), and holding of packed fruits. The minimum floor area for a ton of fruits handled in a packinghouse is 20 square meters. The wooden basket is widely used in Rwanda because it is cheap they are made from indigenous woods and highly available material. However, unlike other rigid containers, it offers the least protection of produce from physical injuries if no preventive measures are employed. It has sharp and uneven surfaces, cannot be stacked on top of one another without crushing the fruits at the lower layer unless wooden cover or wooden divider in between layer.

2.2.5 Seasonality of tomatoes production

Tomatoes are available almost throughout the year in Rwanda. However, there is production peaks and lows in some months depending on the production season and locality. In Kayonza, there are normally three production seasons for tomatoes, from February to May, the risk of diseases and decay due to rainfall is low (high season), the second season is from March to July which is low season and the third one starting in July ending in November and is done in marshlands and is low season, not all tomato farmer grow tomatoes because of unsuitable weather conditions. These farmers have to use irrigation system for that season. Due to the physical aspects of Rwanda, typically hilly with swamps between extensive mountainous areas, that seasonal calendar for tomatoes production is applicable for the whole country. Tomato yields fluctuate from season to season. That fluctuation has implication on post harvest losses because high season results into over supply and wastage caused by poor post harvest handling and inadequate market outlets, state and perishable nature of tomatoes.

Table 2*: Seasonal calendar of tomato production in Kayonza*

Jan.	Feb.	Marc.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov	Dec.
season	Long rainy season				Long dry season			Short rainy season			Short dry
	planting			harvesting high season							
		planting				Harvesting Low season					
						planting				harvesting low season	

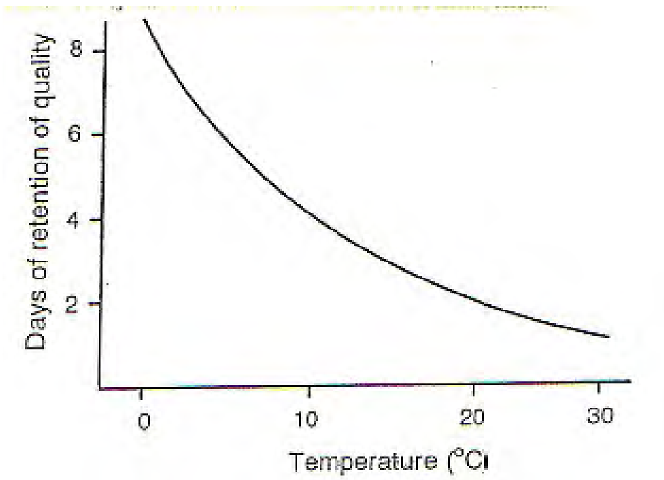
(Source:own outline)

2.2.6 Distribution –Logistics and Transportation

Logistics involve procurement; grading, packing, transportation storage and management in general. Major problems reported in the study area include lack of storage infrastructures. insufficient in transport and logistics, high cost of transportation, no formal grading. Sorting or grading prevents the untimely deterioration and spoilage of the fruits. Mixing poor quality, diseased or damaged fruits with sound ones result to increased incidence of decay because the poor quality and damaged fruits are susceptible to disease pathogens which, together with that in diseased fruits, could contaminate and cause decay of the sound fruits. Mechanically damaged and disease fruits also produce high levels of ethylene which accelerates ripening and senescence. It is not also advisable to mix unripe fruits with ripe ones, particularly during long-duration transport and storage because ripe fruits give off high levels of ethylene that induces premature ripening of the unripe ones.

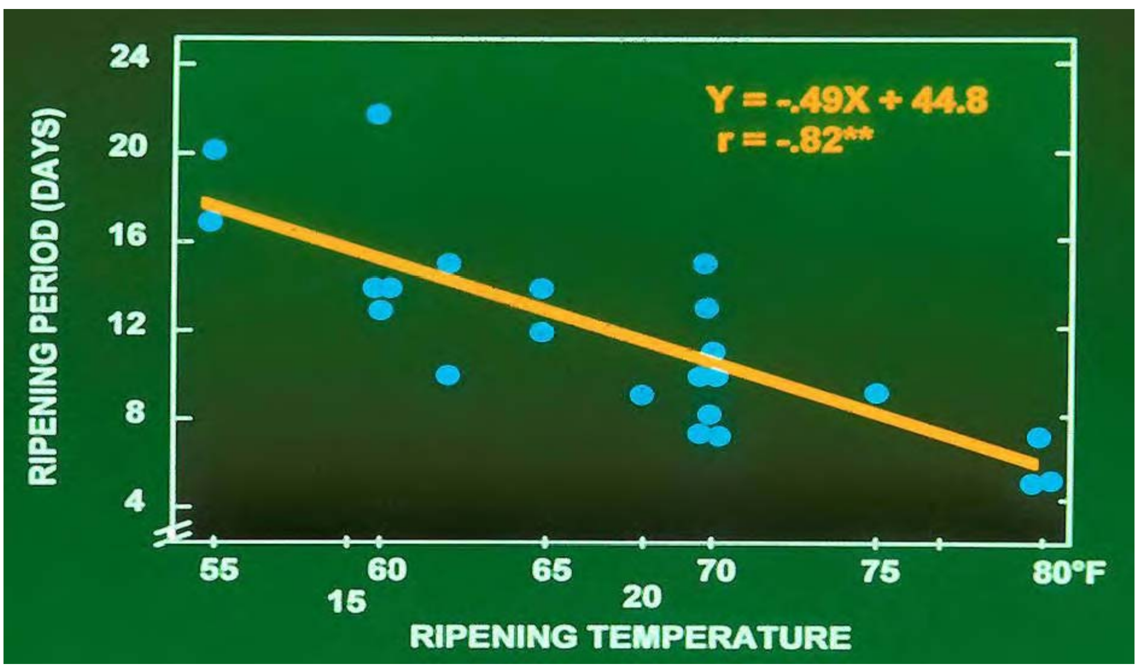
Tomatoes with thick pulp or flesh can withstand rough handling better than those with thinner pulp. If both varieties are packed together in one container, mechanical damage incurred by the thin-fleshed variety may lead to decay and affect the healthy thick-fleshed fruits, besides its effect on enhancing ripening. Some farmers usually grow and harvest two or three varieties at the same time.Buyers move from one farmer to another or meet them to the local market. Tomatoes are transported by road through public transport, Lorries, pick-ups or own vehicles (case of SORWATOM) and all these vehicles are not insulated. Traders prefer using public transport because they are cheaper than hiring a lorry or pick-up. They are packed in wooden baskets or bags of 20-25 kg. After harvesting, the farmers bring their produce to the market for sale. Their mode of transport from field to the market is preferably by wooden baskets, which is the cheapest among the available transport. Packaging is almost absent in the farmers' field. In the market, the middlemen use to pack the tomatoes in bags having no ventilation and send them to distant market. Once the consignment reach the market, damaged and decayed fruits are sorted out either at wholesaler or retailer level and these are sold at throwaway prices if there are any takers.

Figure 6*: The relationship between quality of fresh produce and temperature*



Source: (Acedo and Weinberger 2006)

Figure 7*: Effect of temperature on ripening time of tomato*

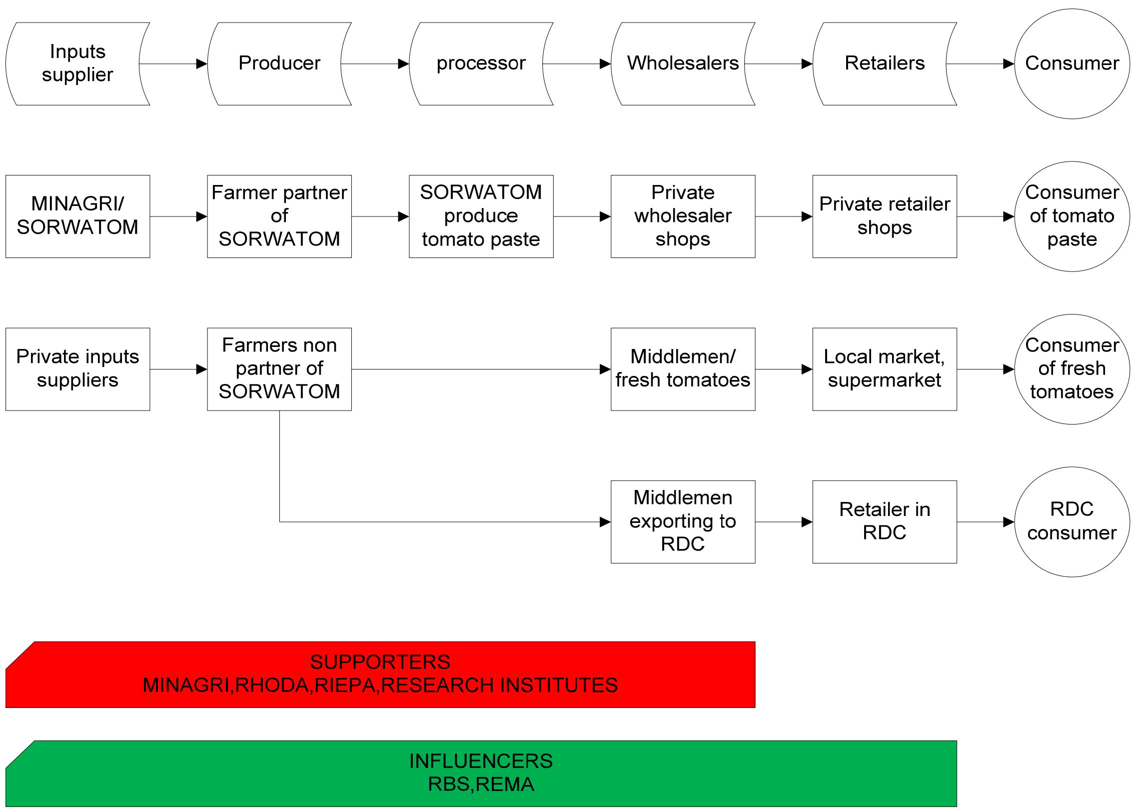


(Acedo and Weinberger 2006)

2.2.7 The tomato supply chain in Rwanda

Tomato distribution channel in Rwanda: There are various local and regional marketing channels for tomatoes in Rwanda. Independent smallholders produce tomatoes for both domestic and regional market. Most of tomatoes are bought from the farms or local market by wholesalers who transport them by either to local market (especially in towns) or to neighbor country (Democratic Republic of Congo).Another group of farmers is partner of SORWATOM factory and signs contract with that factory that offers to them a stable price without considering the season of the production. The price is sixty Rwandan francs (0.07 Euros) per kilogram and the transport is in charge of the factory. The price from wholesalers fluctuates according to the season and varies from twenty to twenty five (0.02 to 0.03 Euros) in high season and one hundred to one hundred twenty (0.11 to 0.14) per kg in low season.

Figure 8: The tomato supply chain in Rwanda



2.2.8 Flow of information, money and product within the chain

Information exchange between stakeholders is very important, between supply chain actors. The types of information that flow between stakeholders in the tomato supply chain is in the form of volumes delivered by producers or purchased by buyers, prices and terms of payment for contracted farmers. The information flow in tomato sector is not well streamlined hence there is no one to take initiative to gather the information. Farmers often lack the necessary information on alternatives marketing possibilities and alternatives product uses, such as drying and other options for value addition. The flow of money is in one direction while information and communication flow in both directions. Growers are disadvantaged in term of information dissemination due to poor communication infrastructures in rural area.

2.2.8.1 Prices

Prices are determined by the buyer for the case of SORWATOM partners and vary with supply and demand, season of production for SORWATOM non partners. Normally prices are high at the low season declining gradually as the supply increases.

2.2.9 Institutional environmental analysis. The role of stakeholders in the sector

Tomatoes being in horticulture sector, that sector will be looked at as an organization that besides increasing production and promotion of horticultural products, management activities, post harvest handling technologies are essential for minimizing post harvest losses and adding value to the product. An organization is a group of people working together to achieve a common purpose. Within an organization, people are able to perform tasks, which were not possible when acting alone According to (Luning, Marcelis et al. 2006). The basic function of an organization is to produce goods and or service that satisfy the needs of customers. The role of stakeholders in supply chain of horticultural products such as tomatoes was gathered from reports, official documents and personal discussions with informants like the managing director of SORWATOM, officers in Rwanda Horticulture Development Authority (RHODA), in Ministry of Agriculture and Animal Resources, and from Research Institutes.

Ministry of Agriculture coordinates the implementation of agricultural, cooperative and rural development policies with the vision of modernizing Agriculture and Livestock to achieve food security. One of the key pillars of this vision is the transformation of Agriculture from subsistence to a productive high value; market oriented farming that is environmentally friendly and has an impact on other sectors of the economy.

Rwanda Horticulture Development Authority (RHODA) coordinates and drives the National Horticulture Strategy, needs assessment and coordination of training needs and assistance requirements. Coordination with Rwanda Investment and Export Promotion (RIEPA) in the conduct of product specific studies designed for investment into the sector.

SORWATOM S.A (Societé Rwandaise de Traitement des Tomates) is the factory that transforms the fresh tomatoes into double concentrate paste 28-30%. It is located in Kigali city and has objectives of improving the tomato industry and cultivation in rural areas, transforming the fresh tomatoes into concentrate and other tomato products. The tomatoes cultivation requires high investment capital and has high risk. SORWATOM supports the producers by giving them the credits of in-puts (pesticides, fertilizers.) and the motto-pumps for irrigation. The credit is paid after harvesting.

Kigali Institute of Sciences and Technology (KIST) imparts Rwandan society with the high skills of innovation as exemplified by different and appropriate technologies. The knowledge is disseminated through training, consultancy, service to the community and applied research.

Institut des Sciences Agronomiques du Rwanda (Rwanda Research Institute: ISAR) post harvest unit, works on roots and tubers, cereals & legumes. An early piece of work was a small-scale cassava flour processing system, which though still in evidence does not appear to under further development. Considerable work was also done on developing possible commercial uses of this flour. It appears that a number of people have been trained on the technology but, as far as is known, there has been no take-up, which is attributed to the inaccessibility of credit.

2.2.10 Hybrid Solar drying technology

Sun drying is the natural method of food drying in the early days. It is still being adopted for preserving agricultural products. This type of traditional drying has many disadvantages, such as loss of nutritional value, loss of germination, enzymatic reaction, which may cause several problems etc. Added to this is non-uniform or insufficient drying leading to deterioration of the products during storage. Though open sun drying is relatively simple, it is dependent on the weather conditions, has slow drying rates and the products being dried are susceptible to contamination. This is especially critical in drying of perishable products such as fruits and vegetables.

At present, several modern drying technologies (such as fossil fuel fired and electrical drying) are available for the preservation of agricultural and meat products. Most of them are, however, not applicable for the developing countries like Rwanda, because of the lack or unaffordable cost of any commercial fuels. In the context of Rwanda, biomass source, such as wood, peat and briquettes are suitable energy source for drying purpose because of its ease access in most of the rural areas.Solar drying of agricultural products has several implications depending upon the techniques to be used and the purposes to be met. In case of Rwanda, the primary requirement is to prevent the surplus of fruits and vegetables from being spoilt through decomposition, so that it can be stored for longer periods of time and then consumed during the lean seasons (Joshi and Gewali 2002). Areas, where plenty of these commodities are grown and then partly wasted as well as the areas, where their demand is big during the lean seasons, are abundant. With the introduction of appropriate drying technology, people living in these areas could be highly benefited.

The other important aspect of solar drying technology is the eventual uplifting of local socio-economy through the creation of sustainable market for such value added agricultural products, which may extend beyond the fruits and vegetables to cash crops, vegetable seeds, spices, medicinal herbs, meat products etc. All these would have a positive long-term impact not only on the local economy but also on the national development as a whole. There is no significant tradition or market for dried fruits and vegetables in Rwanda, yet there is plenty of raw material most of the year. The export demand for the product is strong, particularly if they are certified “organic”. The product is light and compact, high value but low weight, ideal for export from a land locked country (Watkins and Anubha 2007).In the hybrid dryer presented in this study, a biomass stove has been installed at one side of the drying chamber of the basic solar cabinet dryer, adjacent to the collector system. The heat from the stove and the solar panels are aspired by a fan installed at the bottom of the drying chamber. Heated ambient air enters into the drying chamber and then passes through the products to be dried. Hot and moist air from the drying chamber exits through the chimney placed at the top of the chamber.

3. REVIEW OF LITERATURE

This chapter deals with the review of research works carried out on general information about tomatoes, post harvest losses, hybrid dryer for minimizing post harvest losses. A desk study was done by reviewing literature to come up with relevant information that supported the research objective and methods of carrying out the research. This involved the study of relevant sources of information like scientific journals, Government documents and reports from the ministry of Agriculture, RHODA (Rwanda Horticulture Development Agency), books and documents on supply chain management, value chain analysis and marketing as well as Internet search.

3.1 General Introduction on Tomatoes

Tomatoes (*Lycopersicon esculentum L.var*) are the world's most commercially produced and used vegetable crop (Rajkumar, Kulanthaisami et al. 2006). The annual worldwide production of tomatoes has been estimated at 125 million tons in an area of about 4.2 million hectares. It is very important in the economic point of view and hence the global production of tomatoes (fresh and processed) has been increased by 300% in the last four decades (FAO 2005) and the leading tomato producers are in both tropical and temperate regions (Dhaliwal et al., 2003). India's contribution is around 7.6 million tons (http://faostat.fao.org).Rwanda is also a producer of tomato with an annual production of about 764.000 tones both for processing and fresh fruit consumption (data from a survey done by RHODA, 2008).Kayonza district alone produce 160.000 tones.

Table 3*: Vegetables production in Kayonza district*

Type of Vegetable	Quantity(1000 tons)
Amaranths	2.2
Cabbages	80.00
Carrots	25.00
Eggplant	20.00
Spinach	4.00
Tomatoes	160.00

(source: RHODA,2008)

Over the last few years, tomato products have aroused new scientific interest due to their antioxidant activity. Tomatoes and tomato products are rich in health-related food components as they are good sources of carotenoids (in particular, lycopene), ascorbic acid (vitamin C), vitamin E, folate and flavanoids (Rajkumar, Kulanthaisami et al. 2006). They also provide potassium, iron, phosphorous and some B vitamins and are a good source of dietary fiber. They have 90-95% water and the large amount of water also makes the fruit perishable. In a ripe fruit, solids form about 5.7% of the fruit, mainly sugars in the form of glucose and a small portion of acid in the form of citric acid(Rajkumar, Kulanthaisami et al.

2006) . The chemical composition of the tomato fruit depends on factors such as cultivar, maturity and environmental conditions, in which they are grown (Rajkumar, Kulanthaisami et al. 2006). It is a short duration crop, giving high yield. But the excess production results in a glut in the market and reduction in tomato prices. Also, it is highly perishable in the fresh state leading to wastage and losses during the peak harvesting period. The prevention of these losses and wastage is very much important especially due to subsequent imbalance in supply and demand at the harvesting off season and economic consideration (Karim and Hawlader, 2005). Therefore, there is a need to increase the shelf life of tomatoes either in fresh or in processed form using food preservation techniques.

3.2 Post harvest losses

“Losses” are changes in the availability, edibility, wholesomeness or quality of the food that prevent its consumption by people. Losses are caused by biological factors -birds, insects, microorganisms and toxic substances. Changes in chemical constituents, commonly present in stored food, causes loss of color, flavor, texture and nutritional value. Plants or plant parts continue to function metabolically after harvest, but differ from the parent plants in their original environment. Massive postharvest losses might be caused by mechanical damage, handling and packaging, storing, transportation and marketing practices, extreme temperatures, drying equipment or poor drying season, improper atmosphere in closely confined storage, traditional processing, marketing systems and legal standards that can affect the retention or rejection of commodities.

Changes during ripening and senescence such as wilting and termination of dormancy (sprouting) may increase the susceptibility of the commodity to mechanical damage or infection by pathogens. The estimated magnitude of postharvest losses in fresh fruits and vegetables is 5 to 25% in developed countries and 20-50% in developing countries, depending upon the commodity (Smilanick, Kitinoja et al. 2002).

The post harvest loss in vegetables has been estimated to be about 30-40% due to inadequate post harvest handling, lack of infrastructure, processing, marketing and storage facilities (Rajkumar, Kulanthaisami et al. 2006).

The post harvest loss of agricultural products in Rwanda is enormous (25 – 50%). Large quantities of fruits and vegetables are being wasted in the country in the absence of proper transportation infrastructure and appropriate preservation techniques. This is a serious concern for an agricultural country like Rwanda where approximately 91% are dependent upon subsistence farming for their survival. Tomato (*Lycopersicon esculentum*) is a popular and highly consumed vegetable in Rwanda. It is commonly used for table consumption as fresh or cooked dishes and for processing into tomato paste,ketchup (by some women’s associations).

Despite the development of improved varieties with better transport quality and shelf life and the improvement of production systems, the tomato industries particularly in developing countries like Rwanda have not significantly advanced because postharvest losses due to fruit over-ripening, decay and physical injuries remain high. As a consequence, farmers income remain low due to low farm gate prices and retail prices remain high as the losses are passed on to farmers and consumers. Several factors contribute to postharvest losses and some of the technological factors include faulty harvesting and handling practices, poor packaging and transport systems, lack of storage facilities and lack of processing techniques. Therefore, the food processing sector can play a vital role in reducing the post harvest losses by processing and value addition of vegetables which will ensure better remuneration to the growers.

To increase the shelf life of tomatoes, different preservation techniques are being employed that comprise of manipulation of storage temperature and relative humidity, addition of chemical preservatives, protection against air / germ pollution through waxing, dehydration and processing into other products. However, the success of these methods depends on how it meets certain requirements of the product quality for consumption. Therefore, it is essential to preserve the tomatoes by using any of the food preservation techniques and to be made available in an acceptable form throughout the year at relatively minimum cost.

3.3 Drying Technology

Drying is one of the oldest methods of food preservation technique and it represents a very important aspect of food processing. During drying two processes take place simultaneously such as heat transfer to the product from the heating source and mass transfer of moisture from the interior of the product to its surface and from the surface to the surrounding air. The basic essence of drying is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time, normally regarded as the “safe storage period” as reported by Rajkumar and Kulanthaisami(2006).

The drying of fruit and vegetables is a subject of great importance. Dried fruit and vegetables have gained commercial importance and their growth on a commercial scale has become an important sector of agricultural industry (Karim and Hawlader 2005). The advantages of dried foods are illustrated by Rajkumar and Kulanthaisami(2006):

- Extended shelf life because of inhibition of microbial and enzymatic reactions.

- Providing consistent product and the seasonal variations are diminished.

- Substantially lower cost of handling, transportation and storage.

- The dried products size, shape and form are modified and the price is constant throughout the year.

- Dried foods can be packed in recyclable packages; this is not always done with fresh foods.

The dried foods can be used as snacks and other processed foods. But during drying, the changes associated with physical and biochemical structure are inevitable because the food is subjected with thermal, chemical and other treatments.

Drying is one of the most energy intensive unit operations and consequently many research works have been carried out to explore the possible energy utilization. It is obvious that in many rural locations, grid-connected electricity and supplies of other nonrenewable sources of energy are either unavailable, unreliable or, for many farmers, too expensive. Thus, in such areas, food drying systems that employ motorised fans and/or electrical heating are inappropriate (Rajkumar, Kulanthaisami et al. 2006). The large initial and running costs of fossil fuel powered dryers present such barriers that they are rarely adopted by small scale farmers. The optimization of dryers necessitates complete knowledge of the whole drying process, thus leading to energy savings and avoiding environmental pollution by using renewable sources of energy (Rajkumar, Kulanthaisami et al. 2006)

Usage of renewable energy technologies has received considerable attention within the past five years for their potential to help meet basic needs in many countries (Akanbi, Adeyemi et al. 2006). Also, use of renewable energy today is much more desirable because most of the other alternative sources of energy have adverse effect on the environment and are in most cases more expensive (Basunia and Abe 2001). As the sun is the cheapest source of renewable energy and sun drying is still the most common method used to preserve agricultural products in most tropical and sub tropical countries despite the problems and the risk of contamination involved; high food losses ensue from inadequate drying, fungal attacks, insects, birds and rodents encroachment, unexpected down pour of rain and other weathering effects(Rajkumar, Kulanthaisami et al. 2006). However, at present, a large proportion of the world's supply of dried fruits and vegetables continue to be "sun dried"in the open under primitive conditions. Therefore, the quality of the dried product is often degraded seriously, sometimes beyond edibility. In such conditions, solar-energy dryers appear to be increasingly attractive as commercial propositions(Rajkumar, Kulanthaisami et al. 2006) .

3.3.1 Solar dryers

Various investigations have shown that solar drying can be an effective means of food preservation since the product is completely protected during drying against rain, dust, insects and animals(Farkas 2004). But still some obstacles have to be overcome that solar drying will become a technology with a broad dissemination. Although a lot of research work has been conducted during the last decades, only a small number of appropriate solar dryers which can be used by farmers or small scale industries in developing countries are commercially available. Furthermore, there is still a lack of knowledge on how to process fruits, vegetable, fish, etc. in a proper way to ensure a high quality product and to minimize post-harvest losses (Rajkumar, Kulanthaisami et al. 2006).

In solar drying, solar-energy is used as either the sole source of the required heat or as a supplemental source. The air flow can be generated by either natural or forced convection.

The heating procedure could involve the passage of preheated air through the product or by directly exposing the product to solar radiation or a combination of both (Rajkumar, Kulanthaisami et al. 2006). The major requirement is the transfer of heat to the moist product by convection and conduction from the surrounding air mass at temperatures above that of the product or by radiation, mainly from the sun and to a little extent from surrounding hot surfaces (Rajkumar, Kulanthaisami et al. 2006).

In direct radiation drying, part of the solar radiation may penetrate the material and be absorbed within the product itself, thereby generating heat in the interior of the product as well as at its surface, and thereby enhancing heat transfer(Basunia and Abe 2001). During drying, there is a tendency of the food to form dry surface layers which are impervious to subsequent moisture transfer, if the drying rate is very rapid. To avoid this effect, the heat transfer and evaporation rates must be closely controlled to guarantee optimum drying rates (Rajkumar, Kulanthaisami et al. 2006).

3.3.2 Hybrid dryer

The solar–biomass hybrid cabinet dryer is actually a simple solar cabinet dryer with a back-up stove attached to its drying chamber. The stove uses a biomass fuel such as wood, peat or briquettes to generate the required hot air for drying.

Figure 9*: Hybrid solar dryer*

Drying chamber *fan* *stove*

Hybrid drier used to carry out these experiments has been bought by UNIDO to CODECOMA cooperative and consist of:

- solar air collector (18 sq. metres)
- 72 drying trays (= 36 sq. metres total drying surface)
- supplementary heating system: warm air generator (35 kW) and biomass furnace (14 kW)
- Photovoltaic system for electricity generation

Advantages of biomass furnace:
Enormous heating capacity and fast heat distribution
Even burn up and long glow retention
Large combustion chamber
Almost complete wood combustion, with resulting low level of ash accumulation.

4. METHODS OF DATA COLLECTION

4.1 Research strategy:

This research aimed to examine post-harvest losses in tomatoes in selected areas in Kayonza district in Eastern province of Rwanda.
The objectives of the research were to:
1. Determine the extent of post-harvest losses in tomatoes at the farm level
2. Assess the effectiveness of hybrid (solar and biomass furnace) dryer to address these problems for sustainability of horticulture crops like tomato.

4.2 Methodology

Both secondary and primary data have been used to analyze the post-harvest losses in tomatoes in Kayonza district. Hybrid drying experiments of tomatoes were done at CODECOMA cooperative and moisture variations were measured at KIST Food Science Laboratory. Some dried samples were blended in powder at the same Institute.

Primary data were collected from the selected farmers who grow tomato in Kabarondo sector. That sector has high concentration of tomato production and is located far away from SORWATOM factory and the two clusters of tomato growers are there. It was noted that there were no major difference in between various districts in term of post harvest handling facilities, marketing issues and supply chain organization. It was expected that most of desired information could be captured from the selected sector. Thirty famers were selected; fifteen of them were partners of SORWATOM and other fifteen, non partners of that factory. Besides the cultivation of tomatoes, selection criteria at production level were applied to cover a broad mix of farmers. They include the following:

Small scale, middle scale and large scale producers
Members of SORWATOM factory as well as non –members

The survey was done using a questionnaire with the aim of finding out their production seasons, post harvest handling facilities and technologies, transport facilities, marketing channels in relation to post harvest losses.

Secondly data were collected from nine informants with interest in vegetables production and post harvest technologies. The interview was done by verbal questionings of stakeholders who are crucial or possess knowledge relevant to understanding of tomato chain(production, post harvest handling, processing technologies) in Rwanda. The guidelines were based on the research objective and aimed at identifying the causes of post harvest losses at farmer level and the effect of hybrid dryer in minimizing these losses.

They were selected from the following organizations:

From Rwanda Horticulture Development Authority (RHODA) - 2 officers- in charge of vegetables production and another in charge of post harvest technologies

From the Department of Food Science in Kigali Institute of Science and Technology (KIST), one lecturer of Vegetables Sciences and Technology.

From the Centre for Innovation and Technology Transfer (CITT) at KIST- one officer in charge of technology transfer.
From Institut des Sciences Agronomiques du Rwanda (ISAR)-2 officers in charge of post harvest technology.
From SORWATOM factory-director manager of that factory
From CODECOMA cooperative- president of the cooperative.
From the Ministry of Agriculture –one extension officer in Kayonza district

4.3 Data collection

In order to collect data, questionnaires have been created and employed (see appendix).They were developed and pre-tested. Pre-testing was necessary to ensure that all questions were clear such that all interviewees will understand them in the same way. The questions were guided by the research objective and had to provide answers to the sub questions of the main research question in the proposal. It was used to yield data in the following area:

Seasons of production
Seed varieties used
Cost of production
Marketing channels
Storage facilities
Prices fluctuations
Post harvest losses at farmer level
Processing technology
Advantages of solar drying
The qualitative method applied within this research consists of key resource person interviews. These respondents were from some organization involved in horticultural production, Food processing technologies and Research Institute and have understanding on post harvest losses and methods of minimizing theses losses (case study guidelines in appendix).

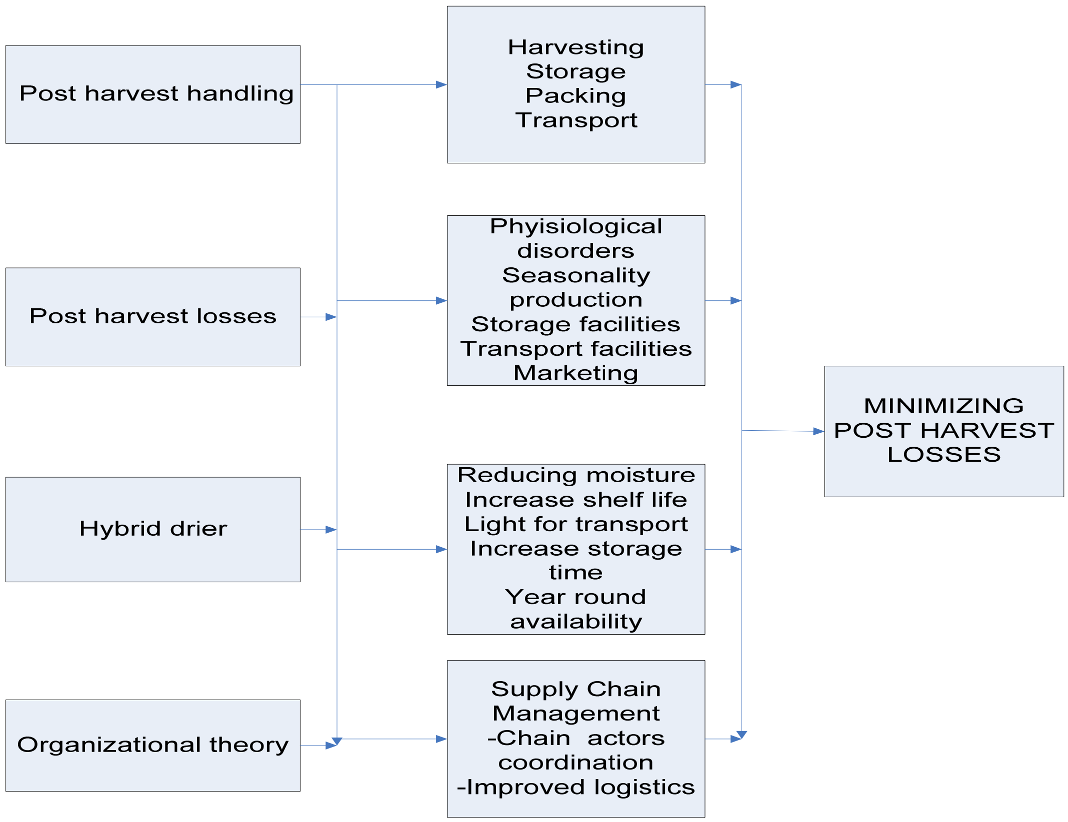
4.4 Methodology for experiments

Fresh tomatoes were bought from the interviewed farmers. Before starting the experiment, the tomatoes were washed with potable water and sliced into circular discs of 6 mm thicknesses using a hand operated adjustable mechanical slicer. The sliced tomatoes were dried using hybrid dryer and the results for moisture variation were recorded every one hour. Sliced tomato samples of 6mm of thickness were kept in the drying chamber of hybrid dryer. The chamber was provided with hot air from both solar panels and the stove. The experiments were carried out between 11:00 and 24:00 h.

4.5 Conceptual research framework

The research framework revolves around the theories of post harvest handling, post harvest losses, effectiveness of hybrid dryer; and these were used as baseline to address the problem of post harvest losses in fresh tomatoes. Based on this, the research develops recommendations about real application of hybrid dryer in order to address the problem of post harvest losses in fresh tomatoes. These recommendations should be implemented by different organizations operating at the macro or meso level in tomato sector.

Figure 10*: Conceptual research framework*



5. RESULTS AND DISCUSSION

In this chapter, data are recorded, analyzed and discussed. The data include those collected during survey, case study, experiments and data from desk study such as journals. reports and internet search during literature review. Several methods and tools including graphs, charts, tables, and models are used in the analysis and discussion depending on the type of data in question.

5.1 Post harvest losses of tomatoes at farmer level

In Kayonza district, the researcher concentrated on post harvest handling techniques, seasonality of tomato production, market channels that lead to post harvest losses. Seasonality in tomato production, inadequate post harvest handling techniques /infrastructures, processing techniques, marketing and storage facilities and the perishable nature of that produce, huge quantity of tomatoes is spoiled within a short period and that affects the returns to the farmer, leading to fluctuation of the tomato selling prices and the availability of tomatoes the whole year round.

The test variables were;
Seasonality in production
Post harvest handling techniques
Processing techniques
Marketing channels
Availability of tomatoes year round
Hybrid dryer for minimizing post harvest losses
Effect of hybrid dryer on farmer income
Effect of hybrid dryer on Transport
Effect of hybrid dryer on availability of tomatoes the whole year round
The objective of the research was to find out the production seasons of tomatoes, the market channels and prices, post harvest handling techniques carried out in the region. Most tomatoes growers in the region are small to large scale farmers. The small scale farmer of our respondent has an average farm size of 1.1ha from which they use0.6 ha for cultivation of tomatoes. The average farm size of the medium scale farmers is 1.75 ha with 1.15 ha under tomato cultivation; the average farm size of the large scale farmers is 3.5 ha and 2ha is under tomato cultivation. The classification on the categories of farmers was done by the respondent based on their own perception or consideration. Tomatoes are mostly grown in Kayonza as a cash crop. Based on quantitative data an average of 70% of the total yield is sold and only 2% is used for private consumption and given to neighbors. Due to perishability of tomatoes post harvest losses at farm level vary from 20 to 30%. There are no post harvest handling techniques, no sorting, no cooling and storage facilities in the region so tomatoes are harvested when they still not very ripe and for that reason farmers prefer varieties that keep longer after harvesting such a ROMA.

Transport from farmer to local market is a critical issue because they are transported in wooden basket or in bags and they packed tightly at high temperature leading to physical injuries and microbial and enzymatic reactions.

Figure 11***: Packaging and Transportation of fresh tomatoes in Rwanda***

Bags and wooden baskets of tomatoes in Kimironko market in Kigali town

A comparison of the prices for the seasons (high and low) from the two categories of farmers (SORWATOM Partners and non partners) was done by using a table.

Table 4*: Selling prices, cost and profits for tomato farmers in high and low season*

	High season SORW.Partner	Non SORW.partner	Low season SORW.Partner	Non SORW.partner
Selling price(Euro/basket)	1.41	0.7	1.41	2.35
Cost (Euro/basket)	0.7	0.6	0.8	1.20
Profit(Euro)	0.71	0.1	0.61	1.15

(source: own compilation)

These figures illustrate that the farmers who are not SORWATOM partners make a very small profit in high season(0.1 euro/basket),whereby in low season they can realize a high profit(1.15 Euros /basket).The fluctuation of selling prices between seasons is high at production level. Due to absence of proper storage and marketing facilities, farmers are forced to sell their produces at throwaway prices. Sometimes farmers do not even get the two way transportation cost, so they would rather dumb their produce near the market area than bearing the transportation cost required for taking the produce back in high season. Tomato cultivation in low season is very risky due to climatic conditions. Consequently, few farmers take that risk but for SORWATOM partners, they receive some support from that factory like motto pumps for irrigation and inputs (fertilizers and pesticides...) as credit that they have to pay after harvesting.

The price fluctuation between the two clusters of farmers in high and low season was checked by T independent tests and presented in error bars bellow:

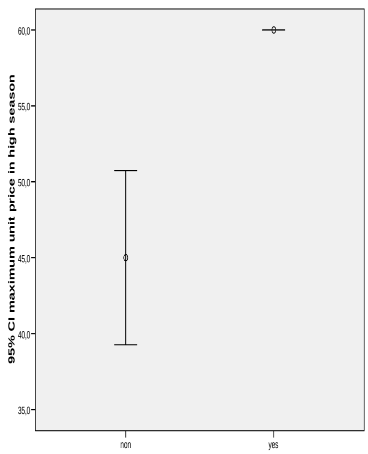
Ho: There is no significant difference in market price fluctuation between SORWATOM partners and non SORWATOM partners in high season

H1: There is significant difference in market price fluctuation between SORWATOM partners and non SORWATOM partners in high season

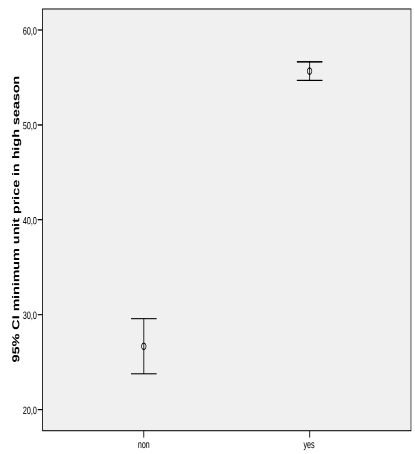
At 5% level of significance (p=0) can reject the Null hypothesis (see appendix 4)

There is significant difference in price fluctuation between SORWATOM partners and non SORWATOM partners whether in high or low season. SORWATOM partners have a permanent buyer, they pre–sign contract and the price is always determined by SORWATOM while the price for non SORWATOM partners is determined by the season, the supply , demand and competition.

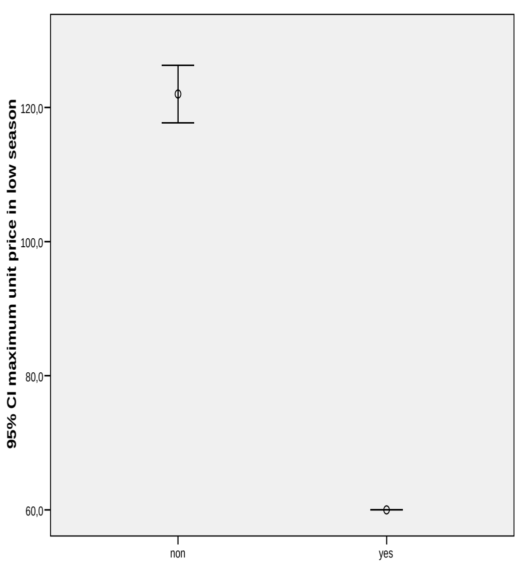
Figure 12*: Price fluctuation according to the season*



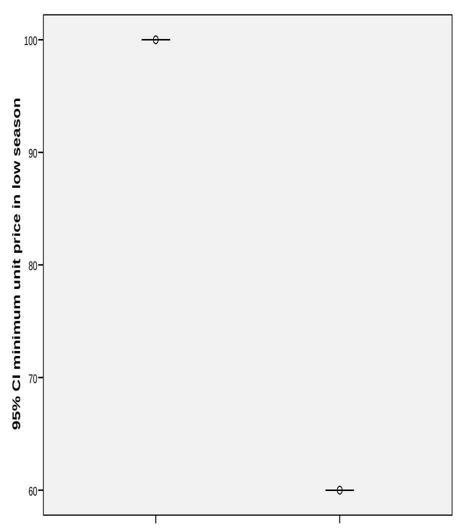
SORWATOM partners



SORWATOM partner



SORW ATOM partners



SORWATOM partner

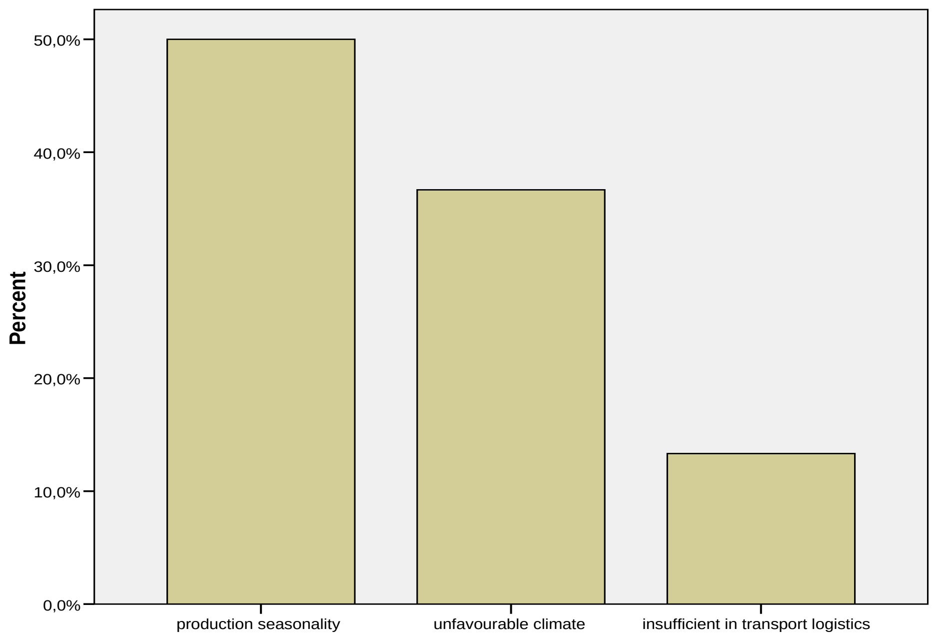


Figure 13*: Main causes of scarcity of fresh tomatoes in local market*

A comparison of the responses between the two clusters of farmers on the magnitude of post harvest losses was done statistically by a chi-square test using SPSS statistical packages.

Test 1: To analyze whether there is difference on market accessibility (pre-signed contract) between the two clusters of farmers.

$\mathbf{H_0}$-There is no significant difference on market accessibility between SORWATOM partners and non SORWATOM partners.

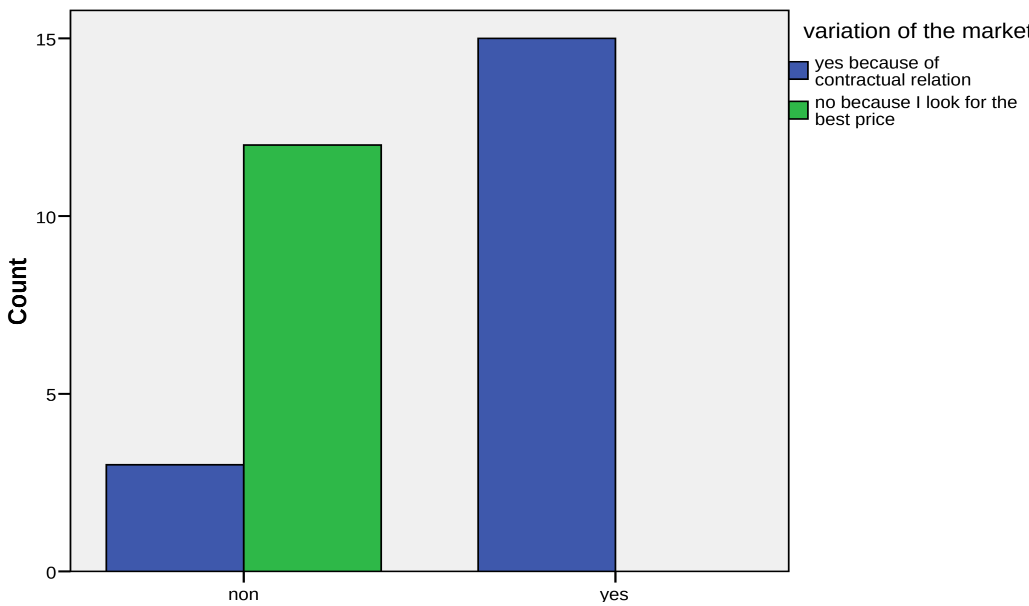
$\mathbf{H_1}$- There is difference on market accessibility between SORWATOM partners and non SORWATOM partners.

The chi-square statistics=0 (appendix 4)

At 5% level of significance (p=0) can reject the Null hypothesis.

Conclusion: there is significant difference on market accessibility between SORWATOM partners and non SORWATOM partners in the study area. The graph shows the difference between the two clusters of farmers in term of selling their fresh tomatoes. SORWATOM partners pre –sign contract with the factory whereby the other group has unstable market.

Figure 14*: Market variation (selling to the same buyer)*



Test 2: To analyze whether there is relationship between the post harvest losses and the Tomato processing factory partnership.

H_0- there is no significant difference in the magnitude of post harvest losses between the SORWATOM partners and SORWATOM non partners in the study area.

H_1- there is a difference in the magnitude of post harvest losses between the SORWATOM partners and SORWATOM non partners in the study area.

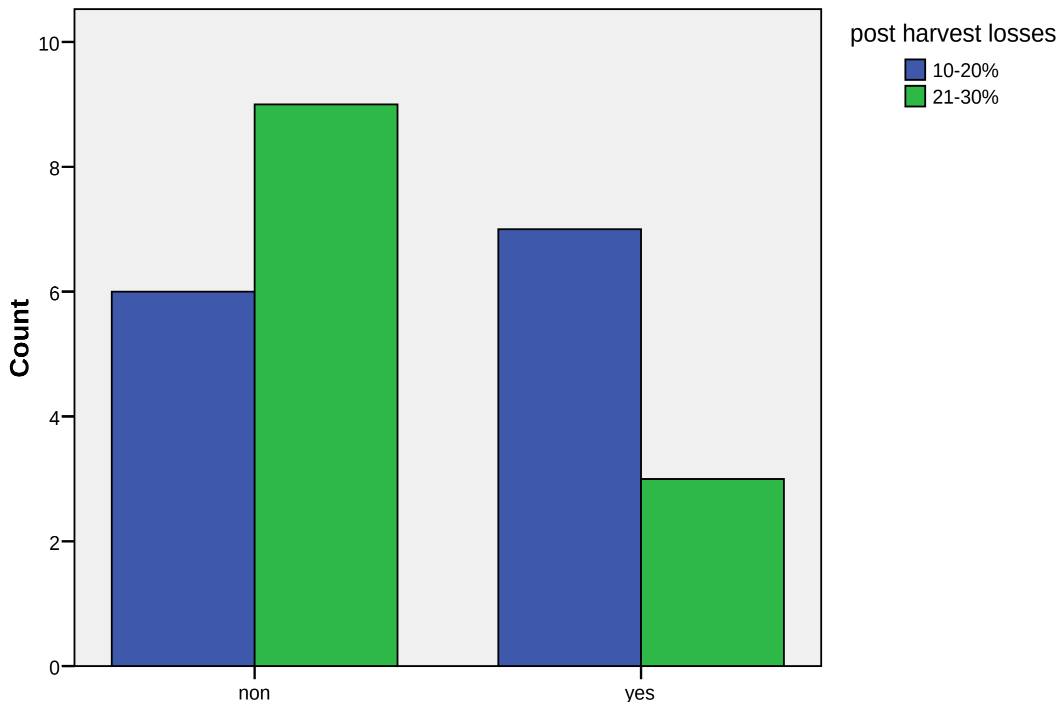
Results:

At 5% level of significance (p=0.144) accept the null hypothesis.

Conclusion:

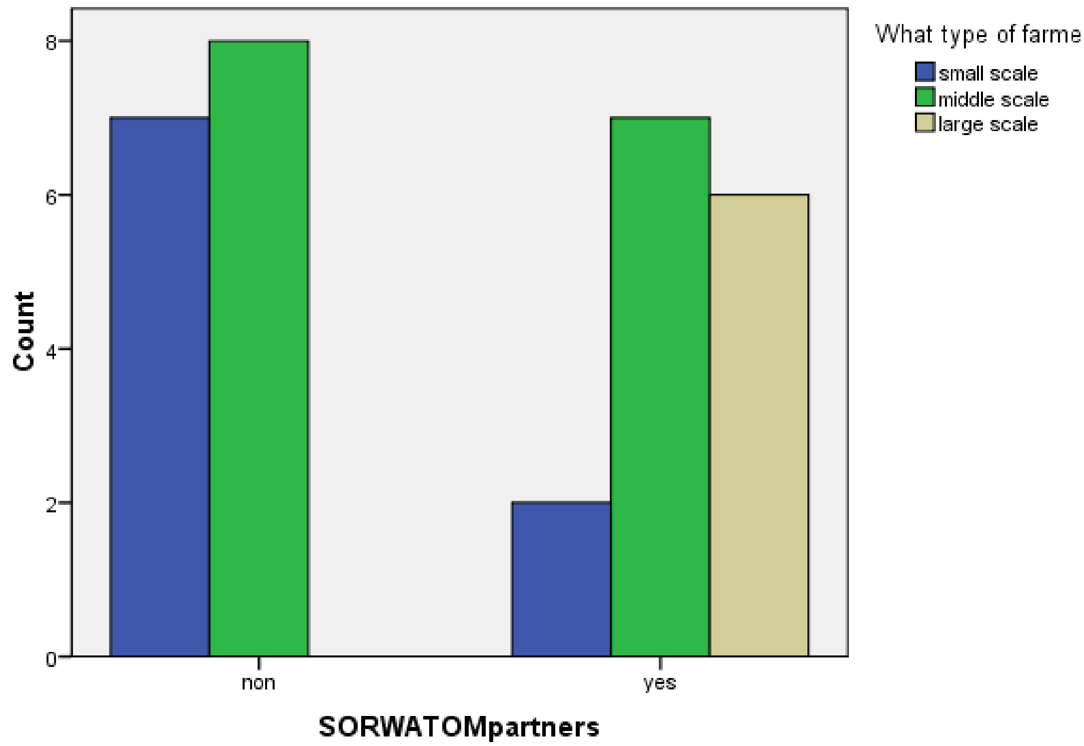
There is no significant difference in the magnitude of post harvest losses between the two clusters of farmers. The graphs show that there is difference but it is not significant from SPSS analysis. The percentage of losses in SORWATOM partner farmers is mainly between 10-20% while in non SORWATOM partner farmers, the percentage of losses range mostly between 21 and 30%.

Figure 15*: Percentage of post harvest losses of fresh tomatoes at farmer level*



The graphs show that a large number of farmers non partners of SORWATOM have the high percentage of post harvest losses(21-30%).Whereby few farmers partners of SORWATOM Partners have that amount of losses. This is could be justified by the permanent market they have.

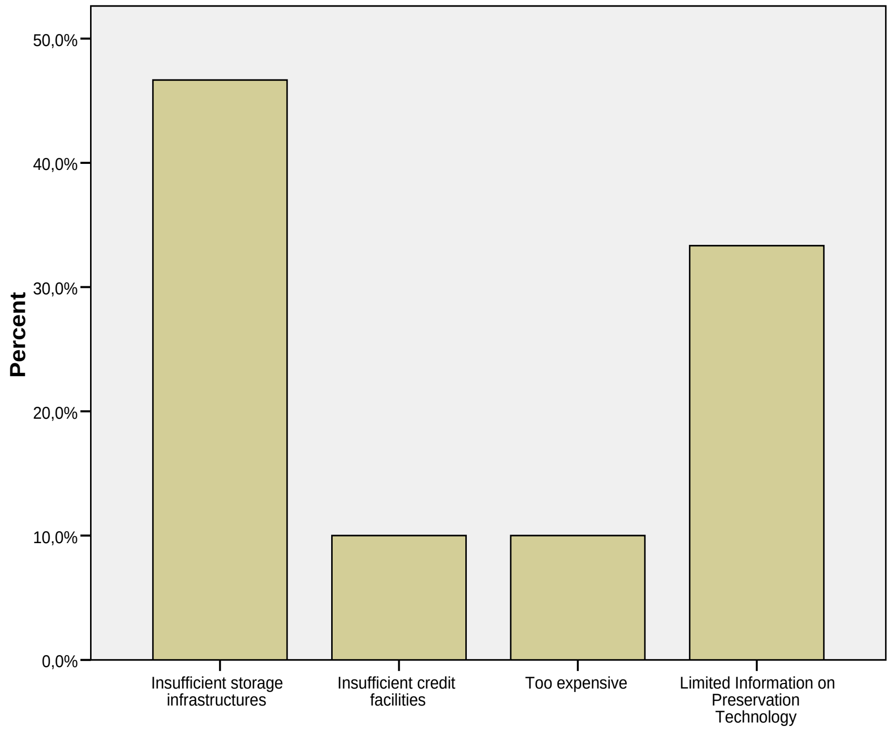
Figure 16*: Categories of Tomato farmers partner of SORWATOM*



The majority of SORWATOM partners are middle scale farmers mixed with large scale farmers and non SORWATOM partners are mainly middle and small scale farmers as illustrated by the graphs.

The non SORWATOM partners denied the partnership with that factory because it gives the same price without considering the season(high and low) .In addition to that the factory is located far from these farmers (about 100 km) and when they harvest it delays to come and pick the product leading to high postharvest losses. They prefer to sell their product to middle men whether at farm gate or at local market without any pre-signed contract.

Figure 17*: Farmers' Constraints for preservation of tomatoes*



Summary of the findings:

From analysis of the results and fields observations, causes of fresh tomatoes scarcity in Rwandese local market is mainly the production seasonality. In high season, tomatoes are plenty and the benefit for the farmer is low, while in low season, there is production of few tomatoes due to unfavourable climate but farmers get a high benefit from it. Due to inadequate storage facilities, limited information on preservation technologies, during the high season, a large quantity of fresh tomatoes are spoilt before reaching to the market. The magnitude of these losses is different between farmers partner of tomato processing factory (SORWATOM) and non partners because of the accessibility to the market. SORWATOM partners have a permanent buyer and their benefit from fresh tomatoes seems not to fluctuate a lot depending on the season.

5.2 Experimental research

The results indicate that drying of tomatoes could be completed within 12 hours in a normal sunny weather (or even cloudy or rainy weather, when drying could be continued with biomass operation). Solar-biomass hybrid dryer seem to be an attractive and reliable alternative way to minimize post harvest losses in fresh tomatoes in Rwanda.

The experimental investigations on drying tomatoes slices have been done. The moisture content of fresh tomatoes was initially 94%, while the dried tomato contains about 9% of moisture (w.b.). The drying time was 12 hours.

The shelf life of the dried products in hybrid drying notably improved compared to fresh product due to reduced moisture content. This eliminates possible deterioration due to microbes or physical injuries.

For the experiment, the dryer was loaded with 36kg of sliced fresh tomatoes as ripe fruits, by spreading them inside in 36 trays (each tray with one kg). The product is dried by using the heat from the solar collector and the stove.

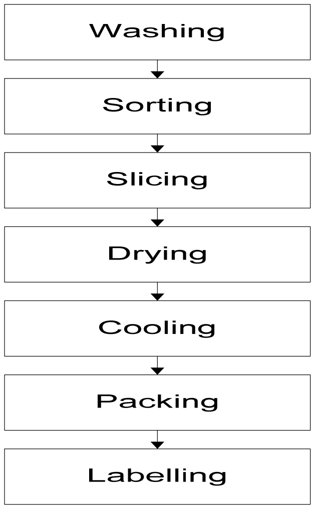
5.2.1 Procedure

Fresh tomatoes were procured from interviewed farmers. The tomatoes were washed with potable water and sliced into circular discs of between 6 and 8 mm thicknesses using a knife. The sliced tomatoes were dried using hybrid dryer and the results are reported

The tomatoes were dry when the raw material / dry product ratio was about 12.5:1. On an average, 80 g of dried products are obtained from I Kg of fresh tomatoes. The yield depends on the dry tomato residue and the degree of drying,25:1 when seeds and the liquid are eliminated before drying(Acedo and Weinberger 2006) . The last operations before storage are: cooling (half an hour at room temperature), bagging (in 100 g cellophane bags, closed to avoid humidity) and labelling. The product must be kept in a dark place to reduce infestation by insects. A sample of dried slices was ground into powder but this tends to cake and the colour is less appealing than the non ground slices.
Three processing recommendations made in the flow-sheet below have to be followed, among others, for all dried/dehydrated products:

1. Let finished products cool down to room temperature for half an hour before packing/bagging;
2. Always store dried/dehydrated products in a dark place.
3. Place dried/dehydrated products in packing materials which have enough barrier effect against moisture transfer and close well.

Figure 18*: Simplified flow-sheet for tomato drying* *Dried tomato slices*




Dried foods store well in airtight containers and will keep up to one year(Fodor 2006)

5.2.1 Thermal efficiency of hybrid dryer

The results of observations from various studies are summarized in Table bellow

Table 5*: Thermal efficiency of hybrid solar dryer*

SN	Particulars	Results
1	Initial weight of tomatoes(kg)	36
2	Final weight of tomatoes(kg)	2.880
3	Latent heat of evaporation of water at the dryer temperature(kJ/kg)	2390
4	Weight of wood used (kg)	10
5	Calorific value of wood (kJ/kg)	17000
6	Solar panel area (m2)	18
7	Solar insulation (kW/m2)	0.354
8	Effective drying time(s)	43200
	Thermal efficiency	17.7 %

$$\textit{Overall efficiency} = \frac{\textit{Energy required to evaporate the moisture content of drying material}}{\textit{Net input of energy}}$$

$$= \underline{(W_1-W_2) \times L_i}$$

$$W_f \times H_f + I \times A_c \times t$$

Where W_1= Initial weight of the tomatoes (kg)

W_2= Final weight of the tomatoes (kg)

L_i = Latent heat of evaporation of water at the dry temperature (kJ/kg)

W_f = Weight of wood used (kg)

H_f = Calorific value of the wood (kJ/ kg)

A_c= Solar panel area (m^2)

I = Solar insulation (kW/m^2)

t = Effective drying time (s)

The net input energy in the denominator is incident solar radiation summed up with energy supplied by biomass sources. The amount of radiant solar energy is determined by the intensity of solar radiation during the drying period and surface area of absorber plate receiving the radiant heat. The surface area of the absorber that is exposed to the solar radiation is constant for a particular dryer and thus the thermal efficiency is dependent only on intensity of solar radiation and type and amount of biomass burnt for drying. As given in the numerator of this relation the only factor that varies from product to product is mass of water to be removed. This result into the different values of thermal efficiencies for the same dryer while operating with different products as drying materials (Gewali, Joshi et al. 2005).

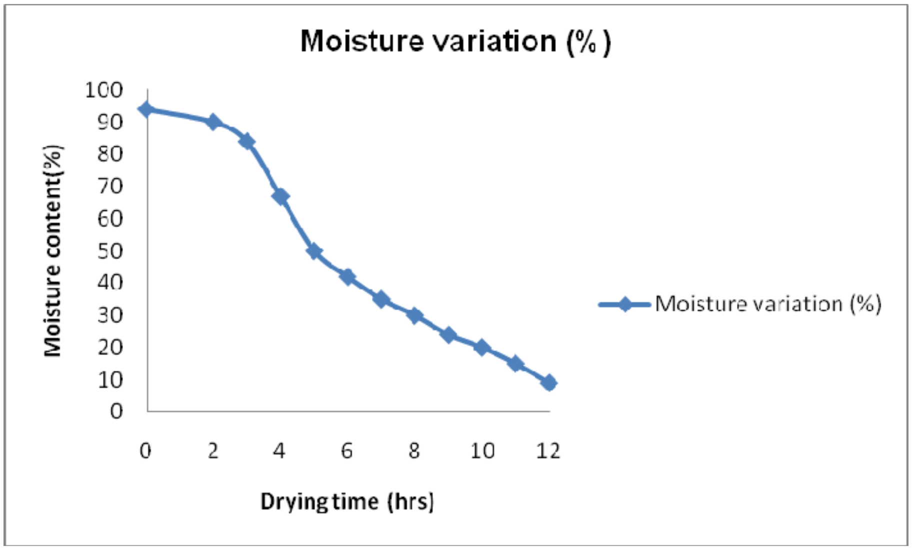
The efficiency of hybrid solar/biomass rack dryer is found as low as 17.7% compared to literature(21.6%)(Gewali, Joshi et al. 2005)

This is because the day, the test was performed, the experiment started late and almost all the moisture was removed by the heat produced by firewood. In this case, high amount of heat was lost through flue gas from the chimney. The efficiency of solar drying system is affected by the properties of drying materials *eg*. moisture content, size, shape and geometry as well as ambient conditions *eg*. solar radiation and temperature, relative humidity, velocity and atmospheric pressure of ambient air.

5.2.2 Moisture content of dried tomatoes

The moisture content of the tomato samples was determined by using vacuum oven at 70 ^oC for 24 h(AOAC 1980). Triplicate samples were used for the determination of moisture content and the average values were reported (see table in appendix 3).

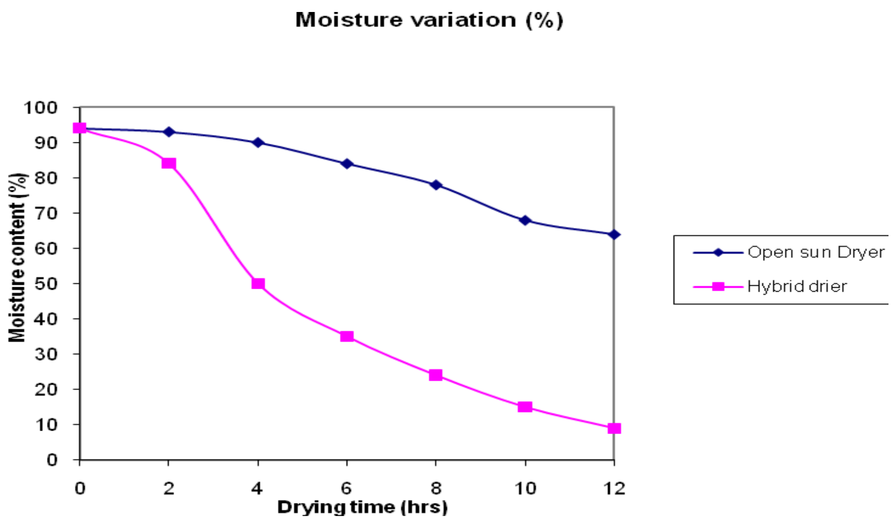
Figure 19*: Moisture variation during hybrid drying of tomatoes*



5.2.2.1 Comparison of hybrid cabinet drier with open sun drying in term of moisture variation with drying time.

The most common form of drying applied in Rwanda is sun drying which is performed by the individual farmers. Sun drying is the spreading of the produce on the ground in the sun but the current method of sun drying has numerous problems. Quality is not consistent; contamination of the produce occurs; losses of up to 40% from insects, animals and weather are common; large land areas are needed and dried food may not be of good quality. The only advantage is the free solar energy.Open sun drying was compared to hybrid cabinet dryer in term of moisture variation during drying and the drying time. Open sun drying experiments were not done during the period of this research, the figures and data used in this report for open sun drying are from a desk study by literature review (see table in appendix).

Figure 20*: Moisture variation in hybrid dryer and open sun dryer*



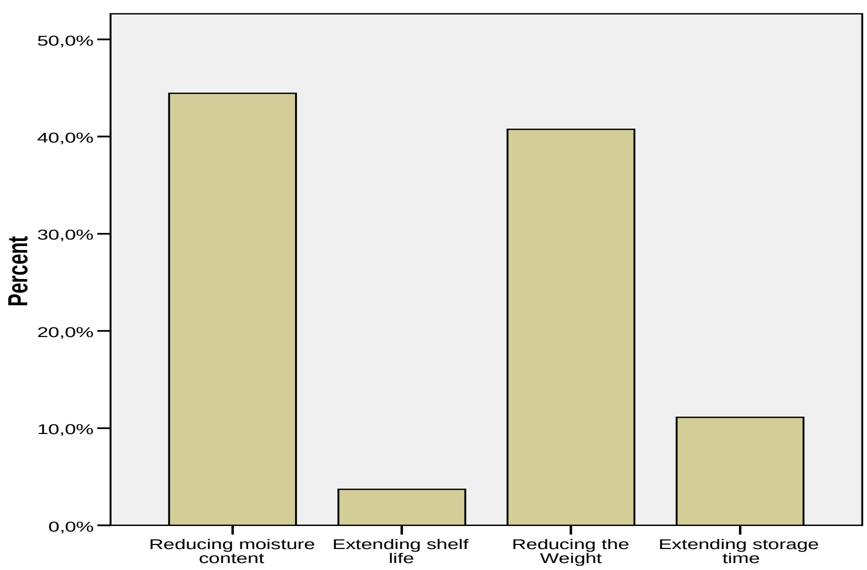
The graphs show that the rate of moisture variation is very low in open sun drying compared to hybrid solar cabinet dryer ,the drying time for open sun drying is very long,3 days (Augustus Leon, Kumar et al. 2002) while 12 hrs are sufficient for hybrid cabinet dryer for achieving 9% moisture content of dried tomatoes.

The hybrid dryer can thus reduce the drying time of tomatoes by about 66% compared to open sun drying while delivering superior quality dried product.

The findings from experiments on the effect of hybrid dryer on minimizing post harvest losses correspondent with the answers got from the respondents as illustrated by the graphs bellow.

5.2.3 Effect of Hybrid dryer on minimizing post harvest losses

Figure 21*: Effect of hybrid solar dryer on minimizing post harvest losses*



Conclusion

The test results presented graphically in this paper show the performance of hybrid dryer. From this experiment, the efficiency of hybrid dryer was found to be 17.7 % with tomatoes as drying material.

The hybrid dryer reduced the moisture content of the tomatoes by 85%.Initial moisture was 94 % and 9% after drying. This reduced the weight of tomatoes enormously; 1kg of fresh tomatoes gave 80 gr after drying. Reduction of moisture content to a safe level allows extending the shelf life of dried products.

The removal of water from foods provides microbiological stability and reduces deteriorative chemical reactions. Also, the process allows a substantial reduction in terms of mass, volume, packaging requirement, storage and transportation costs with more convenience (Watkins and Anubha 2007).

The study concluded that good quality shelf stable dried tomato slices could be produced using hybrid solar dryer. Therefore, the drying processes offer an alternative way of using tomato for consumption.

5.2.4 Cost of dryer and payback period

Financial viability is key to any solar dryer to successfully compete with other dryers. A financial analysis generally includes the cost of dryer (fixed cost), cost of drying (operating expenses) and payback. Solar dryers are generally capital intensive. They can be viable only if the annual cost of extra investment (on the solar dryer) could be balanced against fuel savings, or if the equipment cost could be reduced(Jayaraman and Gupta 1995). The user or dryer designer looks for a favourable combination of cost, energy efficiency, quality, and price of the final product(Crapiste and E. Rotstein 1997).Payback is the measure of time (number of days/months/years) it takes to recoup the total investment made on a dryer, in the form of operational cash inflow. Payback analysis does not measure the profitability of dryer as it does not take the service life of dryer into consideration(Brenndorfer, Kennedy et al. 1987). Continued use of the dryer rather than seasonal use will decrease the drying cost and payback(Arinze, Sokhansanj et al. 1996). Economic analysis on a solar dryer should also incorporate the cost benefits due to improved quality, higher yields, less floor area and quicker drying(Hollick 1999).

Benefit from hybrid solar drying

Table 6: Economic analysis of hybrid dryer

Fixed cost/day	6.8 euros
Variables cost	
Price of tomatoes at low season: 72kg X 0.028euros/kg	2.016 euros
power	2.3 Euros
Biomass	2.3 Euros
Labour	3.5 Euros
Total costs	**19.216 Euros**
Selling prices of dried tomatoes	
From 72 kg of fresh tomatoes,5.76 kg dried tomatoes are produced,5.76kg x4.1 euros/kg	**23.616 euros**
Benefit	**4.4 Euros/day**
After 10 years the benefit could be	4.4 Euros x 365x10=**16,060 Euros**

The fixed cost of hybrid solar dryer tested in this research is 25,000 Euros and it has a warranty of 10 years. According to Visser and van Goor in Logistics: Principles and Practice,the profitability of products is usually assessed according to the contribution a product makes to the contribution margin of the total product range. The contribution margin is the sum of money that is primarily needed to cover the general costs, also known as"overhead".In addition this money is needed in order to realize profit. This "contribution to profit and overhead" can be clarified with the help of the following notation:

(P_i-E_i) = gross margin per unit of product *i*

$(P_i-E_i) x Q_i$=contribution margin resulting from a sold amount Q_i of product *i*

P_i = The sales price of product *i*

E_i = *The variable cost per unit product I (Visser and Van Goor 2006)*

By applying this formula,

the contribution margin of dried tomatoes=**23.616Euros-12.416 Euros=11.2 Euros**

5.3 Case study Results

The qualitative methods applied within this research consist of key resource person interviews. The summary of their responses are:

- Very little processing occurring in the fruit & vegetables sub-sectors leading to high losses of perishables vegetables namely tomatoes.
- Supply chain requires organization and introduction of best-practice.
- Lack of the technical capacity necessary for the addition of value and for minimizing post harvest losses in tomato sector is the major constraint faced by farmers.

- Insufficient resources to undertake technology transfer, inadequate knowledge about the existing technology, insufficient reference material, limited existing research skills or experience are major constraints in extending services related to post harvest technologies by supporters in Horticultural sector.

The domestic market for dried tomatoes is small; Rwanda is unusual in having no tradition of drying fruit and vegetables as a means of preservation. It has been argued that the reason may be that two rains per year and plenty of valley-bottom marshland capable of producing crops throughout the year together meant that, historically, the need for preservation in this way never arose.

However, internationally there is a healthy market for dried fruits and vegetables.
To access this market would require the creation of a high-quality rural drying industry using simple solar-based technologies, and an associated formal sector dry-packaging capacity that would add value in terms of quality control, cosmetically-attractive modern packaging and access to high-volume export markets.
Rwanda is land-locked and dependent on air or overland road transport. The cost of a container shipped from the US to Mombasa in Kenya is approximately 66% of the cost of onward shipment from Mombasa to Kigali. The same is therefore true for any bulk exports.
Thus the ideal export products are of low volume & weight per unit of cost/value added. Dried fruit and vegetables fulfill this requirement, since only minimal water content is being transported.

This was confirmed by the report on Needs Assessment and Action Plan Study for Building Capacity in the Food Processing Industry(Watkins and Anubha 2007) by Rwanda and World Bank. This statement gives reason to the application of hybrid dryer in minimizing post harvest losses and creating market opportunities for tomatoes for the year round.

5.4 Tomato farmers participation in the supply chain and chain coordination

There is no coordination in tomato chain. Farmers non partner of SORWATOM operate individually, there is no contractual business relation, and there is no cooperation between farmers and other actors of the chain. The price is set by the quantity supplied and the competition. For SORWATOM partners, the price is determined by the factory.
Public extension services considered as chain supporters showed a deficient support in tomato chain in the research area. The tomato farmer is just a chain actor doing only production without being involved in other activities of adding value to his product (sorting, proper handling…) and in the management of chain. There is inadequate information flow among stakeholders. This is due to the fact that horticultural industry in Rwanda is at the embryonic stage.

6. CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The research concluded that post harvest losses of fresh tomatoes in Rwanda range from 10 to 30 % at farmer level .The causes of these losses are mainly inadequate storage facility and limited information on post harvest handling technologies.Fluctuation of the volume and prices due to seasonality production of fresh tomatoes plays a role in causing post harvest losses. The poor or inexistent linkage between stakeholders in the tomato chain was identified by the key resources informants as another handicap that increases the post harvest losses. Good quality shelf stable dried tomato slices could be produced using hybrid dryer. The moisture content of fresh tomatoes was reduced to a very low level, from 94 % to 9 %.The weight was reduced from 1000 g of fresh tomatoes to 80 g of dried product.

It is concluded that hybrid dryer reduced the weight and the volume of fresh tomatoes thus facilitating the transport. From the research, it is also concluded that the storage time of dried tomatoes is increased due to decrease of moisture content. The reduction of moisture content increase the microbiological stability and the physiological disorders related to high moisture content. The drying time to come up with that moisture was only 12 hours, very short compared to drying in open sun dryer which is 36 hours.

Considerable reduction in drying time is the major advantage reported with this hybrid dryer. While overcoming the limitations of solar drying during cloudy days, the solar-biomass hybrid dryer also enables drying during night-time. The facilitating of continuous year-round operation of the dryer increases the utilisation of the dryer, and improves the financial viability of the hybrid dryer considerably.

Considering (a) the short drying time; (b) the reliability of the drying system; (c) superior quality of dried product due to enclosed and continuous drying, as well as steady drying air temperature(Leon and Kumar 2008); and (d) almost 100% of the drying energy demand met from renewable sources of energy (solar and biomass energy), therefore hybrid dryer could be a useful device for minimizing post harvest losses and the value addition of tomatoes in Rwanda

6.2 Recommendations

Raising vegetable yields such as tomatoes in Rwanda will not improve food security if post harvest losses remain high because the produce cannot be safely processed and stored. In addition to that, farmer's income remains low due to lack of value addition to their tomatoes to make them sustainable and logistically manageable. Appropriate technologies need to be developed and applied to process and store tomatoes without utilizing large amount of electricity as it is unavailable in rural area of Rwanda.

The following are recommended to vegetable sector stakeholders:

1. Farmer cooperative: Structured and well managed farmer cooperatives are necessary to negotiate sales contracts for their members, to produce and process for an identified market, rather than to sell what they have already produced and processed and also seeking new market opportunities that offer higher level of income. Development agencies, donors and NGOs place emphasis on well structured and managed cooperatives. For these reasons, farmers should organize themselves in cooperatives to get support from donors, Development Agencies and NGOs for buying a hybrid dryer for minimizing post harvest losses of their products and to process high volume.

2.Ministry of Agriculture and Animal resources: Extension Services Start a horticulture extension program to reduce post-harvest losses by establishing a group of specialized

experts in the field of post-harvest physiology to instruct local extension workers how to reduce post-harvest losses by using hybrid solar dryer .
Through organizing short courses and trainings, producers must learn how perishable tomatoes are, the proper stage and method of harvesting, field handling, processing, packaging and transportation.
They should be asked to put more effort into new post harvest handling practices like sorting, grading and minimizing physical injuries and addition of value to the tomatoes and making it available the whole year round.

3. Rwanda Horticulture Development Authority should encourage private entrepreneurs to invest in horticulture and adding value to tomatoes for producing higher value products for export and local markets appropriate for a land-locked country. The establishment of a dry packing factory that purchases from a large number of rural cooperatives dried tomatoes would add further value by means of packaging while simultaneously giving rural producers access to high value and high volume markets.
Carrying out market studies in internal markets to identify niche markets for dried tomatoes, market requirements and consumer expectations

4. Research Institutions and Universities (ISAR, KIST) in collaboration with the Ministry of Agriculture and Animal Resources, RHODA, should focus more on designing prototypes of new technologies such as hybrid solar drying and transferring them to small and medium enterprises.

Design and prototyping should consider the feedback from clients and potential retailers. This, in turn, would help meet the Government's objective of providing employment and income-generating opportunities in rural areas without pushing people off the land and into urban slums.

To improve the acceptability of the solar dryer among the farmers, it is necessary to develop a large scale solar dryer, which is economically attractive. The system should have maximum utilization factor, i.e. it must be of multipurpose use to share the cost of the dryer.

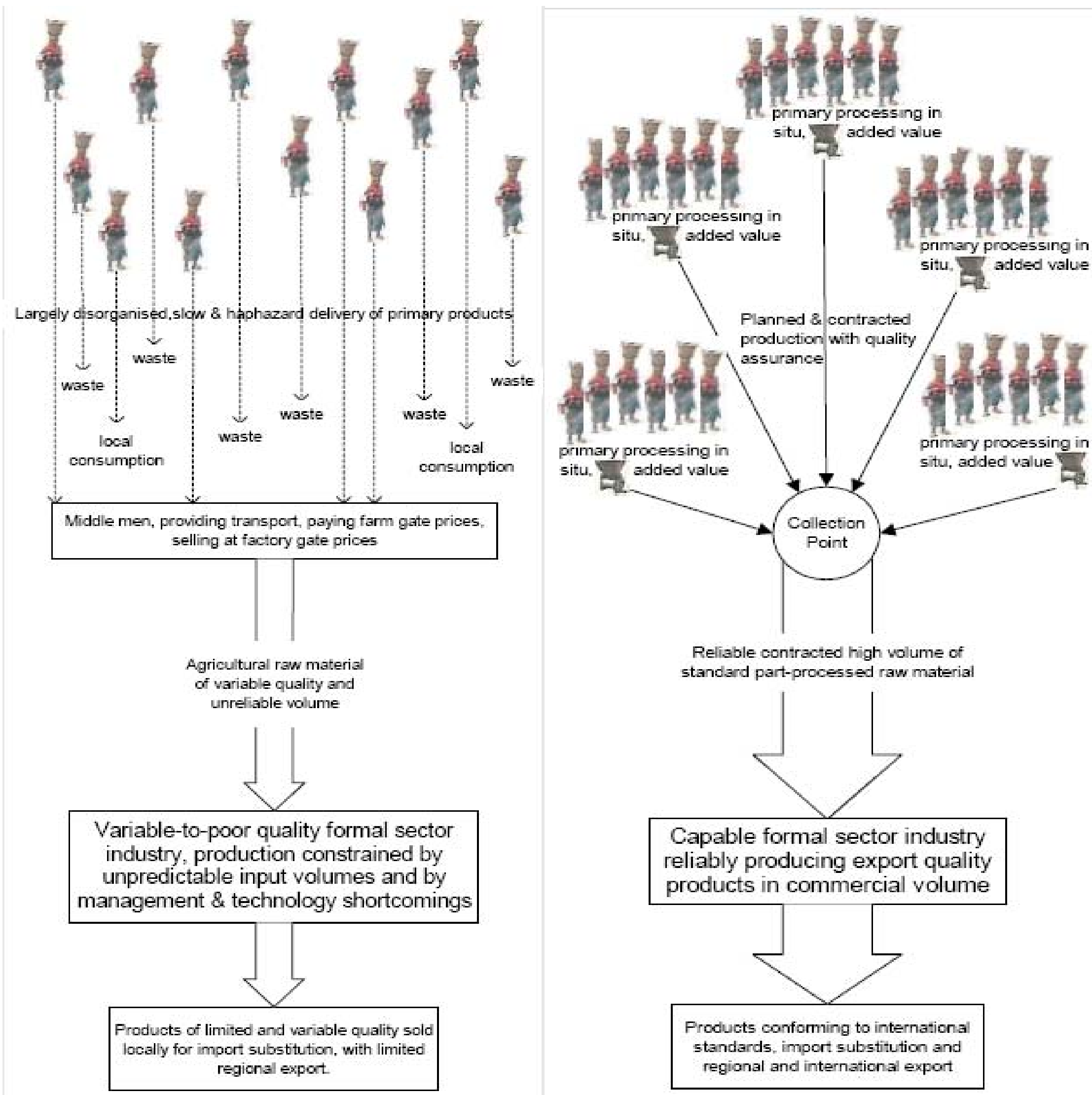
The linkage between them should be developed and strengthened as well the linkage between these supporters and all actors in the chain to improve chain coordination and chain management.

To improve the function and management of the marketing system, concerted efforts should be undertaken by the government to formulate policy on the development of national and regional horticultural (tomatoes) marketing and commercialization projects.

Finally, legislation is required to improve quality and performance of the dried product.

Figure 22*: The opportunity for the development of tomatoes hybrid drying in Rwanda*

Current situation **Recommended strategy**



Source:(Watkins and Anubha 2007)

Future research

Future research and development is needed into making and facilitating tomato business partnerships and linkages between producers, retailers/processor in developing countries like Rwanda to respond to the requirements of consumers with respect to quality, safety, timing, varieties, and volumes. Research on how to increase smallholder participation in production for the market, and expand employment to raise by building more effective supply chains.

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APPENDIX

QUESTIONNAIRES AND CHECK LISTS

1. QUESTIONNARE TO THE TOMATO FARMER

Respondent:

1. How much acres do you cultivate in total?

2. Do you consider yourself as a…………..farmer?

a. small scale b. middle scale c. large scale

3. On how much acres do you produce tomatoes?

4. Are tomatoes the most important crop for you?

a. the most important crops b. among the most important crops c. no important crops

5. Which varieties do you cultivate?

	variety	Actual acre	Reason for cultivation (code)	Available seed quality(code)	Number of seasons/year (which months)	Yield per season	% of yield selling to market	% of yield for own consumption	% of yield lost
1						1 2 3 4			
2						1 2 3 4			
3						1 2 3 4			

Code for reason of cultivation 1= high demand 2=cheap in production 3=low pershability 4=easy to get seeds 5= high yield	Code for seed quality available 1=high seed quality 2= average seed quality 3= low seed quality	Code for % of yield 1=<20% 2=21%-40% 3=41%-60% 4=61%-80% 5=>80%

6. Could you give me an estimation of the total costs you have to produce tomatoes?

a. season: from…………………to………………(RwF/season)

b. season: from……………….. to…………….(RWF/season)

c. season: from……………….. to…………….(RWF/season)

7. Where do you sell your tomatoes?

a. farm gate

b. collection place in the village

c. local market

d. wholesaler market

e. retail market

f. SORWATOM

g. other (specify)

8. To whom do you sell your tomatoes?

a. directly to the consumer

b. vender groups c. wholesalers

d. retailers e. road side seller

f. processing factory(SORWATOM)

g. supermarket

h. Restaurants/Hotel

i. schools

9. Do you mainly sell to the same buyer(s)?

a_1. yes, because of family relations

a_2. yes ,because we developed good business relations

a_3. yes , because of contractual relation

a_4. Other (specify)

b_1. no, because I look for the best price

b_2.no, because I don't know anybody I trust

b_3. Other (specify)

10. How much do you get usually per unit?

a. high supply season : from……………..to……………..RWF per …….(unit)

b. low supply season : from……………..to……………..RWF per …….(unit)

11. Who or what in your opinion determine the price?

a. me b.other party c. Other (specify)

12. How much do you get usually per unit

a. high supply season :from ………to…….RWF per ……(unit)

b. low supply season : from ………to…….RWF per…….(unit)

13. If no, but I would need to, what hinders you?

a. too expensive

b. no possibility here

c. other(specify)

14. What is the root causes of the scarcity of the fresh tomatoes in your local market?

a. Production seasonality

b. Unfavourable climate

c. Insufficient in transport logistics

d. Pest and diseases

e. Others (Please specify)………………………………………

15. If you need to, do you have access to and adequate place to store your tomatoes?

a. yes and it is enough

b. yes but not enough

c. no and I don't need

d. no, but I would need

16. In your opinion what are the major constraints that you face in preserving your fresh tomatoes?

a. Insufficient storage infrastructures

b. Insufficient Credit facilities

c. Too expensive

d. Limited information on Preservation Technology

e. Others (Please specify)………………………

17. Among all answers that you gave, which constraint has the biggest (1), second biggest (2),Third biggest (3), importance for you?

18. What quantity of your tomatoes production spoil before you sell them?

How much?.........%

19. Have you heard about any form of technology for preserving tomatoes? Which one?

a. Non, I did not

b. Modified atmosphere

c. Solar drying

d. Canning

e. Processing in tomatoes products f. Others (Please specify)……………………..

20. In your opinion, how can solar drying help to minimize post harvest losses of your fresh tomatoes?

a. By reducing the moisture content

b. By extending the shelf life

c. By reducing the weight

d. By extending storage time

e. other (please specify)…………………………………………………………………..

21. How can this affect your income from tomatoes production?

a. Minimizing losses

b. Easier for transport

c. Selling my product the whole year round

d. Others (Please specify)…………………………………………

2. CASE STUDY GUIDES

Available technologies and services on minimizing post harvest losses

- What are the main activities of the organization
- What are the services being extended to tomatoes farmers in term of post harvest handling technology
- What do they know about hybrid solar drying technology
- What are the constraints of farmers in accessing and implementing hybrid solar drying technology
- What are the constraints in extending services to tomatoes farmers relative to minimizing post harvest losses by hybrid solar drying?

3. MOISTURE VARIATION IN HYBRID DRYER

Drying time(hrs)	Moisture variation (%)	Removed moisture (%)
0	94	0
2	90	4
3	84	10
4	67	27
5	50	44
6	42	52
7	35	59
8	30	64
9	24	70
10	20	74
11	15	79
12	9	85

Moisture variation in open sun dryer and in Hybrid dryer

Drying time(hrs)	Open sun dryer (%)	Hybrid dryer (%)
0	94	94
2	93	84
4	90	50
6	84	35
8	78	24
10	68	15
12	64	9

4. SPSS OUT PUT

Group Statistics

	SORWATOMpartners	N	Mean	Std. Deviation	Std. Error Mean
maximum unit price in high season	non	15	45.000	10.3510	2.6726
	yes	15	60.000	.0000	.0000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
		Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
maximum unit price in high season	Equal variances assumed	24.889	.000	-5.612	28	.000	-15.0000	2.6726	-20.4746	-9.5254
	Equal variances not assumed			-5.612	14.000	.000	-15.0000	2.6726	-20.7322	-9.2678

Group Statistics

	SORWATOMpartners	N	Mean	Std. Deviation	Std. Error Mean
maximum unit price in low season	non	15	122.000	7.7460	2.0000
	yes	15	60.000	.0000	.0000

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means					
									95% Confidence Interval of the Difference
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Upper
maximum unit price in low season	Equal variances assumed	4.639	.040	31.000	28	.000	62.0000	2.0000	57.9032
	Equal variances not assumed			31.000	14.000	.000	62.0000	2.0000	57.7104

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
SORWATOMpartners * post harvest losses	25	75.8%	8	24.2%	33	100.0%

SORWATOMpartners * post harvest losses Crosstabulation

Count

		post harvest losses		Total
		10-20%	21-30%	
SORWATOMpartners	non	6	9	15
	yes	7	3	10
Total		13	12	25

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	2.163(b)	1	.141		
Continuity Correction(a)	1.128	1	.288		
Likelihood Ratio	2.210	1	.137		
Fisher's Exact Test				.226	.144
Linear-by-Linear Association	2.077	1	.150		
N of Valid Cases	25				

a Computed only for a 2x2 table
b 1 cells (25.0%) have expected count less than 5. The minimum expected count is 4.80.

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
SORWATOMpartners * variation of the market	30	90.9%	3	9.1%	33	100.0%

SORWATOMpartners * variation of the market Crosstabulation

Count

		variation of the market			Total
		0	yes because of contractual relation	no because I look for the best price	
SORWATOMpartners	non	1	0	14	15
	yes	0	15	0	15
Total		1	15	14	30

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	30.000(a)	2	.000
Likelihood Ratio	41.589	2	.000
Linear-by-Linear Association	13.679	1	.000
N of Valid Cases	30		

a 2 cells (33.3%) have expected count less than 5. The minimum expected count is .50.