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POSTHARVEST LOSS ASSESSMENT OF TOMATOES IN RWANDA

APRIL 20, 2018

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FEED THE FUTURE INNOVATION LAB FOR HORTICULTURE

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COVER PHOTO:

Tomatoes in market. Photo by Jesse Daystar for the Horticulture Innovation Lab.

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Agribusiness Associates

Started by Mr. Gurbinder Singh Gill, Agribusiness Associates is an international development consulting firm focusing on overcoming the biggest challenges in the agricultural sector. The firm has special expertise in offering comprehensive solutions to the agribusiness sector for enterprise development. ABA has worked in public-private partnerships, seed industry, technology adoption, capacity building and providing strategic advisory services.

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ABBREVIATIONS & ACRONYMS

CSAM	Commodity Systems Assessment Methodology
HACCP	Hazard analysis critical control points
PEF	The Postharvest Education Foundation
PHI	Postharvest intervals
RAB	Rwanda Agriculture Board
RALIS	Rwanda Agriculture and Livestock Inspection and Certification Services
RBS	Rwanda Bureau of Standards
RPC	Returnable Plastic Crate
SSC	Soluble solids content
WFLO	World Food Logistics Organization
ZECC	Zero Energy Cool Chamber

1. EXECUTIVE SUMMARY

Tomatoes are a widely produced and consumed horticultural crop in Rwanda with consumption on the rise. Rwanda is a net importer of tomato. The production is seasonal and the crop is highly perishable. Tomatoes have been identified as a priority crop for the Reducing Postharvest Losses in Rwanda project, as previous studies have noted high losses (WFLO 2010).

To understand the postharvest losses in the tomato value chain, the project conducted three types of analysis – Value Chain Analysis, Commodity Systems Assessment Methodology (CSAM) and Environmental Lifecycle Analysis.

Tomato sales and distribution is a fragmented system and large players are rewarded. Traders and wholesalers play an integral part in the tomato industry, moving the crop from the farm to the markets. The market rewards big players such as large Farmers who have wholesalers and retailers buying directly from their farm. This allows them to command the best prices due to volume and quality. Smaller players are unable to attract the interest of wholesalers or large traders and have to sell at the village markets. For smallholder farmers increasing quality and quantity and organizing themselves for better bargaining powers, would be key to success.

Tomatoes have a wide range of potential processed and value-added products, including sauces, jams, ketchups, paste, and dried. The development of a vibrant processing industry would help develop the industry as a whole, by increasing the number of tomato Farmers (and thereby its importance in the economy) as well as providing steady, all-season demand and the ability to absorb on-season overproduction.

Improved postharvest handling has a strong role to play in improving saleable volumes by increasing both the quantity and quality of tomatoes. Field work estimates from the Commodity Systems Assessment methodology show that farmers are losing on average 21% of their crop during harvest. At the collection point, another 11.5% of tomatoes are lost. At the wholesale level 10% of tomatoes are culled out and at the retail level 13.6% of tomatoes are discarded. Improving postharvest handling and storage practices will reward each actor along the value chain by increasing the quantity and quality of tomatoes.

Postharvest losses is a complex problem and an integrated solution is needed to mitigate losses across the value chain. To reduce postharvest losses, farmers and traders need to be educated on harvesting practices and postharvest handling and storage. Entrepreneurs are needed to provide postharvest handling and storage equipment including cooling technology.

Transportation solutions are also required, as tomatoes are damaged further as a result of being overloaded onto trucks using poor packaging.

Postharvest losses from tomatoes does not only lead to the loss of saleable and consumable volumes but also translates to more land, water, fertilizers, chemicals and other inputs. Per tonne of tomatoes produced, 21 kg of fertilizers are lost due to postharvest losses. Tomato losses also account for 86 cubic meters of water per tonne of tomatoes. This number represents the amount of water consumed to produce the amount of tomatoes that are lost per tonne of tomatoes delivered to the market. Reducing postharvest losses is key to reducing the environmental impact of agriculture and conserving limited resources.

Summary of postharvest losses and quality problems for tomato

Inputs	• Availability of quality affordable seed on the market has been a limitation to the farmers. The farmers are using regenerated seeds, which at times are up to 3rd generation seed. This greatly lowers seed productivity as the seeds realize less resistance to pests and diseases.
Farmer and Trader Knowledge of Postharvest Management	• Tomatoes are harvested red ripe and soft, with little shelf life remaining. • Tomato packing and repacking occurs several times, which greatly reduces the quality at farm level. Handling was observed to occur up to 27 times on one farm before transport to the wholesale market leading to reduction in quality by the time of arrival to the consumer. • Proper storage after harvest at the farm is one of the major limitations • Lead time between harvest at farm level to customer is approximately 1 day, leaving approximately 2 to 3 days of shelf life. If any delays occur, this leads to additional postharvest losses.
Transportation	• Tomatoes are packed and transported in large baskets leading to various losses along the chain. • Trucks are overloaded for the transport of produce for long distances.

Cold Storage	• There are no cold chains or cool storage facilities for tomatoes.
Farmer Organization	• Farmer cooperatives are not properly organized, which has led to lack of bargaining power for selling their produce to traders.

Recommendations for Reducing Postharvest Losses

Tomatoes are one of the most well-studied horticultural crops, and past research has identified many appropriate handling practices and improved technologies. Four major recommendations are provided to guide the project.

1	**Training of trainers (capacity building) in improved practices.** Value chain players involved in tomato production should be trained in harvest indices, postharvest handling, use of improved containers, sorting/grading, and use of shade. In general, training on production, harvest and postharvest best practices is required.
2	**Demonstrations that are recommended for the Postharvest Training and Services Centers on cost effective practices for reducing postharvest losses in tomatoes include:** ● Use of shade (various types of simple, low cost structures and portable shade such as market umbrellas) ● Use of improved containers for transport and marketing (smaller sizes, stackable baskets, plastic crates) ● Innovative transportation solutions, especially for traders handling small volumes ● Zero Energy Cool Chamber (brick and sand, 100 kg capacity) for temporary cool storage ● Small-scale tomato processing methods (solar drying, sauce making, juices)
3	**Postharvest agri-business opportunities for tomatoes should be promoted. These include:** ● Trader/grower partnerships, where improved tomato production, harvest practices and postharvest handling on the farm leads to

	increased profits for both the growers and the traders. ● Catalyzing entrepreneurs to provide postharvest storage and management services including packaging, handling, cooling technology and better transportation. ● Local manufacture of tomato paste, sauces and juices (with flavors, package sizes and prices targeted to local consumer preferences). ● Smallholders need training on farming as a business

2. INTRODUCTION

Data from the World Bank, Rwanda (2014) reveal that in Rwanda, agriculture is the main support of the economy and is crucial to the growth of the country and its poverty reduction. The agriculture sector accounts for 39% of gross domestic production, 80% of employment and 63% of foreign exchange earnings.

Various estimates say that up to 40% of food is lost in the postharvest stage. Tomato is among the most popular vegetables produced in Rwanda and it is sold on the domestic market both in fresh and in processed form. Domestic demand is increasing because of tomato processors. Tomatoes are produced in many districts of Rwanda (see map). Production has increased from 135,000 tonnes in 2010 to 154,000 tonnes in 2014 (FAOSTATS queries http://www.fao.org/faostat/en/#data/QC). Yields have increased since MINAGRI reports in 2008, but they were still relatively low at about 20 tonnes/ha (last reported data is for 2014).

Two-thirds of Rwanda's tomatoes are produced in the Eastern Province, with the rest shared almost equally between the Western and Southern Provinces.

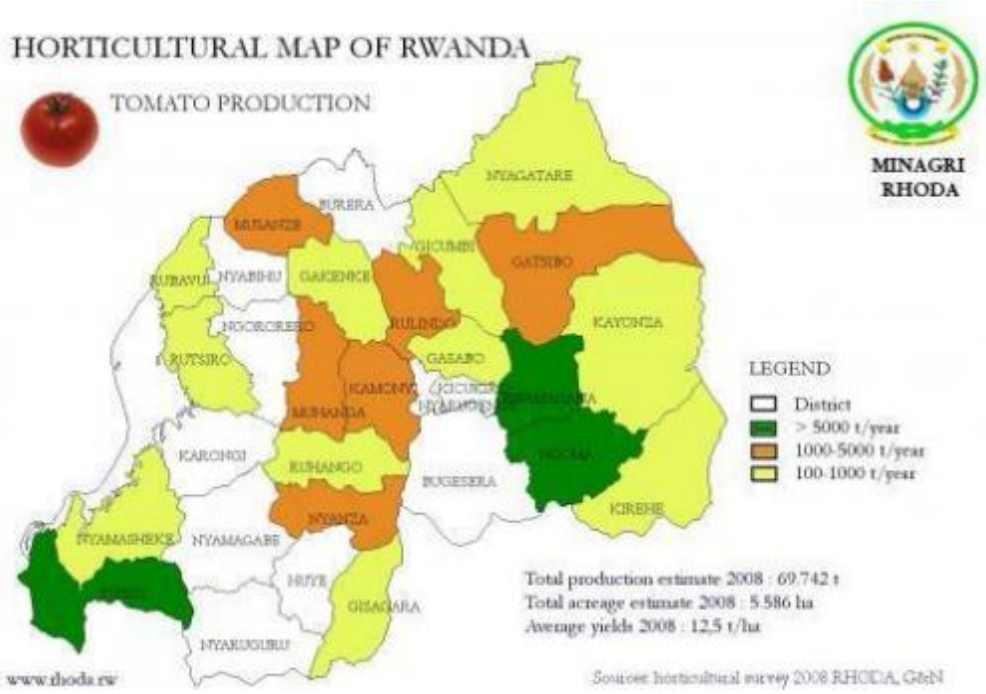


Figure 1: Tomato Production Map

Importance of the crop in Rwanda

Tomatoes are an important horticultural crop in Rwanda with consumption on the rise. The production is primarily in open field and therefore bound by seasonality. Typically, tomatoes are produced during 3 seasons each year, while 4 seasons of production is possible with irrigation. The three growing seasons are Season A and Season B (with harvests in May/June and December/January respectively) and Season C which refers to marshland production (minor in comparison to Seasons A & B) (EU 2015).

Tomatoes are produced on a total area of 7,600 ha, according to FAOSTATS (2014). A Baseline Survey of Horticulture Organizations in Rwanda (EU 2015) determined that approximately 240,000 households are estimated to be involved in tomato production, though approximately 30% of all production is destined for home consumption. Most Farmers are small-scale independent farmers or cooperatives.

Rwanda is a net importer of tomatoes from neighboring countries such as Uganda, the Democratic Republic of Congo and Burundi. The demand for fresh tomatoes is increasing due to economic growth and rise of urban middle class. Table 1 below illustrates the production, yield and area harvested as published by FAOSTATS.

Table 1: Importance of tomato in Rwanda

Year	Production in 1000Tons	Yield in hectogram per hectare	Area harvested in hectare
2008	41	73,460	5,586
2009	130	235,911	5,500
2010	135	207,692	6,500
2011	102	152,872	6,705
2012	115	169,118	6,800
2013	123	196,306	6,281

The areas that grow tomatoes in Rwanda include: Bugesera, Rwamagana, Kayonza, Rusizi, Nyagatare, Gatsibo, Burera, Musanze, Nyanza, Nyamasheke, Huye and the main varieties grown include Roma, Cherry and Plum tomatoes (Source: Fortune of Africa).

Currently the vast majority of tomato cultivation is open field and greenhouse production is rare. Around 2011 there was a push for greenhouse production, supported by the Belgium aid agency, BTC. Many of the cooperatives that received them and the associated support later abandoned the greenhouses and the project did not have the impact it had hoped for. Start-up is costly, but once they are established and the farmers are trained, greenhouse production is easier than open field cultivation, and can produce a far superior quality of tomatoes, and on a year-round, constant schedule.

Tomato production is mainly for the domestic market. Approximately 20-30% of the production is used for home consumption, while 70-80% is sold domestically. There are no formal international exports of tomatoes, and while some regional exporting occurs in border areas during high season, statistics are not available. Rwanda is a net importer of tomatoes; according to official statistics, the country imported 800 tons in 2013, mostly from Uganda and Tanzania, although the real amount is probably much higher when informal trade is taken into account. Rwanda remains an importer of tomatoes mainly due to uneven production throughout the year.

The country is divided into three growing seasons, of which the main two are Season A and Season B (harvests in May/June and December/January respectively), while Season C refers to marshland production (for tomatoes, minor in comparison to Seasons A & B). This seasonal production pattern poses a strong challenge to the effective functioning of the industry. It creates situations of both over- and under-supply, resulting in price fluctuations throughout the year. At a macro-level, this is the main challenge facing the industry.

Uneven supply is exacerbated by the relatively low barriers to entry: new Farmers may jump in, in imitation of neighbors who are seen to be profiting from the crop. This can result in overproduction in one year, then underproduction the following year, as unsuccessful farmers exit.

Consequently, tomato production suffers from extreme price fluctuations, both within the year (due to seasonality of production) and between years (due to influx and exit of Farmers). Farm-gate prices can range from 100 – 400 frw/kg, and at the wholesale level the basket (intebo) can sell from between 10,000 to 80,000 francs. Price fluctuations lead to uncertain incomes, increased loss and waste as harvest becomes economically unviable, and high rates of abandonment by Farmers, making production planning difficult. This leads to uncertainty of supply for traders, wholesalers and retailers.

Currently the vast majority of tomatoes are sold and consumed fresh, with little to no

processing existing in the country. Historically, tomato production in Rwanda was partially driven by the processing plant Sorwatom, a tomato paste Farmer. This company engaged considerable numbers of farmers in tomato production between 2006 and 2011, but their subsequent bankruptcy (2011) resulted in an oversupply of tomatoes as many growers lost their main, stable client. Many Farmers consequently abandoned production. Sorwatom has since re-opened production under new management, but does not purchase tomatoes locally; it imports paste from China and repackages it for the Rwandan market.

Tomatoes are relatively difficult to grow compared to other horticulture products, for example carrots or onions, mostly because of quick perishability, but also due to their susceptibility to disease. The crop is highly perishable because of a fragmented value chain and lack of postharvest technologies. A recent study of the tomato value chain in Rwanda showed that the shelf life for tomatoes was only 1 to 3 days, as they were stored on the ground covered by canvas (van Dijk, 2016). Past assessments have reported 20 to 25% losses of tomatoes are common due to lack of temperature management and use of very poor quality containers (WFLO 2010).

According to the visits made to stakeholders, the Nyagatare District is among the top tomato Farmers in Rwanda, with access to a modernized irrigation system that allows production of up to 4 crops per year, but marketing is still a challenge for farmers, wholesalers and retailers.

3. VALUE CHAIN ANALYSIS

Methodology

In order to gain the correct insights and provide the basis for analysis of key constraints and challenges, the following tools were used:

1) **Literature Review** – of Rwanda agriculture and horticulture reports to date, including the *Strategic Plan for the Transformation of Agriculture in Rwanda Phase III* and the *Draft National Horticulture Policy and Strategic Plan* (2014). Statistical excerpts from the detailed E*U Baseline Report Survey on Horticulture* (2015) were also used where it pertains to tomato and farmers in general.

2) **Interviews** - the bulk of the methodology and work came from a series of interviews with key actors at each stage of the value chain, including but not limited to:
    a. Farmers / Farmers (small, medium, large; coops; companies)
    b. Input supply agents and brokers
    c. Financial institutions concerned with horticulture in general
    d. Government ministries where applicable
    e. Government institutions, including National Agricultural Export Development Board (NAEB) and Rwanda Agricultural Board (RAB)
    f. Agriculture Extension workers (district level)
    g. Traders in the selected crops (where applicable)
    h. Wholesalers in the selected crops (where applicable)
    i. Exporters (where applicable)
    j. Processors
    k. Transport agents
    l. Retailers
    m. Others as applicable

3) **Site visits** to farms, markets and factories

Each Value Chain analysis was developed in conjunction with a local team who were trained on the methodology, as well as with representatives of the partner organizations in the Reducing Postharvest Losses in Rwanda project – National Agriculture Development and Export Board, Rwanda Agricultural Board (RAB) and the University of Rwanda.

Findings

This section breaks down each stage of the tomato value chain (Inputs; Production; Harvest and Postharvest; Marketing and Distribution; and Processing) as well as Government/Operating Environment. Owing to the relatively low level of development of the industry, many of the issues identified are not specific to tomatoes in particular, but rather to horticulture in general.

GOVERNMENT / OPERATING ENVIRONMENT

As noted in the Horticulture Overview, the government has a strong and vital role to play in developing horticulture in general and tomatoes in particular. Several government policies aimed at intensifying general agriculture are positive for the tomato industry. The Ministry of Agriculture and Animal Resources (MINAGRI), via RAB, takes a role in supplying pesticides and there are subsidy schemes for purchase of fertilizers (*Umurenge*). Land and village consolidation schemes also have a positive impact for horticulture as well. The government also provides subsidies for purchasing irrigation equipment, and has a policy of irrigating marshlands to provide year-round land for horticulture (and other crop) production.

Formal financing remains a key challenge for all horticulture sectors due to the inherent riskiness of the industry, as well as lack of knowledge or background amongst traditional banks. A culture of financing groups at the village level does exist (*Ikimina* associations) and provides the possibility for Farmers to invest collaboratively in inputs and production materials.

As noted in the overview section, horticulture (especially for domestic consumption) is a priority growth area for the government, and has attracted the support of international aid agencies; in particular the U.S. Agency for International Development and the Japan International Cooperation Agency (JICA) are active in this sphere, though none have any programs specifically targeting tomatoes.

INPUTS

Three inputs – seeds, fertilizer and pesticides – are available in the country. Two large international sellers (Balton and Agrotech) create a competitive environment and both are growing their horticulture practices. Balton estimates that currently 30% of their business is horticulture-related. Both of the large input suppliers have trained agronomists on staff that act as educators as well as demand stimulators for their products (and therefore for the industry as a whole). East African Community (EAC) and Common Market for Eastern and Southern African (COMESA) agreements have increased imports of inputs and decreased prices in this region.

Nonetheless, several constraints exist:

Inputs are pricey and not always accessible

- There is good availability in Kigali, but limited distribution in rural areas, and getting to Kigali is an issue for many rural farmers (time, cost).
- Input providers generally sell to larger companies and coops (only ~ 20% of their sales are to small farms or individuals)
- Specialized inputs for tomatoes – grass, mulch, wood sticks – are not readily available

- Only 16% of all farmers use pesticides and 18% used non-organic fertilizer[1]

Seeds are not accredited

- Many small farmers use their own seeds and there is no quality control or certification for locally grown seeds; only 13% of all farmers use improved seeds[2]
- RAB has no seed accreditation system for tomatoes, nor seed multiplication programs specifically for tomato
- Connected to the seed issue, there is lack of knowledge of appropriate tomato varieties for Rwanda

Lack of knowledge around appropriate input usage

- Specifically for fertilizers and pesticides, there is a low level of knowledge of appropriate use for tomatoes.
- There are cultural reasons for low levels of adoption of inputs (there is no history of pesticide use, in particular).
- Tomatoes are disease-susceptible, and even after pesticide use, diseases can develop and spread rapidly. Diagnostic tools are not available.

All of the above combine for low levels of use of pesticides and inorganic fertilizer which impact both yield and product quality (size; disease).

PRODUCTION

Many of the challenges highlighted under INPUTS affect production as well, and as tomatoes are a relatively new crop, and there exists a low level of planting and best practices for production.

Despite support programs, irrigation is underutilized

- Only 13% of small-scale vegetables growers (not only tomatoes) practice irrigation, versus 42% of larger scale farmers[3]
- Equipment is costly and has low availability and/or awareness (sprays, hoses, pumps and generators)

Tomatoes can generate an "Imitation Mindset"

- In recent years, many Farmers jumped into production without fully considering supply and demand, leading to overproduction
- Little production information or market information about supply and demand (before harvesting)

[1] Feed the Future 2011

[2] FTF 2011

[3] FTF 2011

There is limited Greenhouse Production

- As noted in the industry overview, most tomato production in Rwanda is open-field. The seasonality of open field production (with low levels of intensification) leads to imbalances in supply and demand
- Greenhouses for cooperatives do not have a good history in Rwanda, owing to their relatively high failure rate, but in the long run they may be one of the solutions to the challenges faced by the industry

Combined, the challenges highlighted in INPUTS and PRODUCTION produce a low-quality product – uneven, small size and often marred by disease. While improvements in postharvest handling will decrease loss and waste, and improve yield, there is as much, or more, work to be done at the production level in order to grow a higher quality product.

HARVEST AND POSTHARVEST

Postharvest losses remain high throughout the country and are high for tomatoes: an estimated 40%-60^ of tomatoes are sorted out before retail sales, as shown in the CSAM study.

Key postharvest challenges for tomatoes in Rwanda include:

Cultural practices regarding harvest increase losses

- A preference or belief that tomatoes should only be picked when red
- Low understanding or use of off-vine ripening (also related to lack of storage options; see below)

Farmers may understand the importance of improving postharvest handling, but adoption is low:

- Low use of appropriate handling and packing materials (sheeting, crates, etc.), due to cost and lack of awareness
- No subsidies for postharvest materials exist, similar to ones for input and production issues
- A domestic packaging plant is under development, though it is uncertain whether its products will be of use to tomato farmers
- Postharvest handling has not been a priority for government or aid-supported initiatives; according to the 2015 European Union survey, less than 1% of respondents cited having received this type of support.
- A well-organized extension service system could be the conduit for improvements in this area.

Most sorting occurs at the retailer / trader level:

- Only rudimentary sorting occurs at the farm-level

- More so than proper sorting and packing, *time* is most important to wholesalers or traders when collecting tomatoes

Lack of storage use and options:

- Low knowledge about storage best practices
- Government or project-sponsored collection centers for horticulture are underutilized; even in tomato "hot spots", volumes and yields are too low to justify or guarantee the use of such centers. Various projects have already shown what *doesn't work* with regards to collection centers, so there is a demonstrated learning curve.
- Government (and private sector) land consolidation and production intensification efforts will increase volumes, thereby increasing viability of cold store and/or collection centers, but this is a long-term initiative.
- Small Farmers rarely harvest daily, resulting in high levels of on-vine spoilage

Road conditions and transport issues increase postharvest losses

- Accidents on bikes or while carrying loads on heads are common
- Distance to travel is far and hilly terrain increases difficulties with transport
- Small roads still need improvement

=> All of these challenges contribute to shortening the already short and fragile life of the tomato, and exacerbate waste and losses.

MARKETING AND DISTRIBUTION

Overall, the tomato marketing and distribution system is fragmented and there are no central players in the value chain to extend to farmer involvement**.** Despite its fragmented nature, there is some dynamism in this part of the chain, and it provides a good living for a group of tomato entrepreneurs, in particular larger scale Farmers and wholesalers/retailers.

There exist several initiatives in this space that may improve the functioning of the system in the future: MINAGRI has a project (e-Soko) to provide daily updates on market prices of crops in Kigali markets, although it appears to be underutilized. The future Kigali Wholesale Fruit & Vegetable market (a NAEB project) aims to develop a professional horticulture wholesale market with high cleanliness and quality standards.

Key challenges include:

Fragmented and informal marketing and distribution system

- Low volumes and scattered production leads to a strong reliance on middlemen and agents

- The largest profits and the least risk accrue to wholesalers
- Multiple repacking moments after the farm gate cause tomatoes to degrade and increase losses because of physical damage.

Price fluctuations, due to imbalance of supply and demand

- A central problem of the industry, as highlighted in the industry overview

Many small-scale Farmers lack a commercial mindset

- Extension services and cooperatives/Farmers are often focused on production, not on marketing and developing business skills that may enable them to take a forward position in the marketing and sales of their crops
- Low levels of professionalism and low use of contracts
- Low levels of market info. regarding prices; E-Soko is an online system, and therefore is underutilized by Farmers who have no access to the internet. This is balanced by high rates of cell phone penetration that make accessing market price information possible

Low level of market access

- Physical access: High cost of transport and difficulties with transport (hilly terrain); high cost of vehicle, bicycle and motorbike leasing and/or purchase
- Better markets access: low product quality and quantity are significant barriers to accessing better paying markets

Physical markets are often chaotic and crowded

- Lack of space and cleanliness concerns
- Lack of transparency around costs and taxes
- Despite many initiatives, only an estimated 6% of villages have a dedicated market space for agricultural products

PROCESSING

Tomatoes have a wide range of potential processed and value-added products, including sauces, jams, ketchups, paste, and dried. The development of a vibrant processing industry would help develop the industry as a whole, by increasing the number of tomato Farmers (and thereby its importance in the economy) as well as providing steady, all-season demand and the ability to absorb on-season overproduction.

The following graphic shows potential processing options for tomatoes (note that it refers to well-developed production sectors, where generally open field tomatoes are considered of higher quality and only destined for fresh consumption.

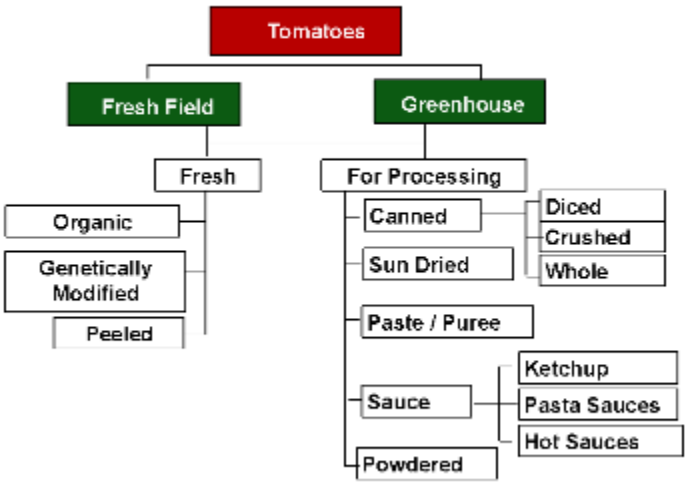


Figure 2: Tomato Processing Options

As noted in the OVERVIEW, the only industrial scale tomato processing plant closed in 2011, and since that time there is only small production at Urwibutso Enterprises in Rulindo (making ketchup). Industrial quantity demands are high, and quality requirements are usually high as well (tomato processing is not always a secondary quality outlet). Financing constraints apply to processing as well.

Key challenges for the development of a processing industry include:

Risk of supply-led, rather than market-led, investment decisions without proper strategy

- "We have the tomatoes, so let's do something with them"
- Repeated attempts to reach SORWATOM were unsuccessful, but it can be assumed that they no longer purchase locally due to supply issues (quality & volume) and no longer manufacture locally due to high domestic cost of production; any new investment in this space would need to show how it would overcome those constraints
- No artificial measures should be employed to grow a local tomato processing industry
    - i.e. No banning of imports, or excessive support to local start up industries

High cost of manufacturing in general

- General high cost of manufacturing in Rwanda (packaging, machines, electricity) means local products probably unable to compete with imports
- Small local market
- Cheap imports from Kenya and Uganda (ketchups and sauces) and Italy (paste)

TOMATO ACTORS AND SYSTEMS

A. FARMERS

FARMER SEGMENTATION

There are several types of farmers involved in the tomato industry.The area for the small farms undoubtedly includes those that only grow a small portion of tomatoes for home consumption, therefore dragging down the average size under cultivation for commercial purposes.

The following provides an overview of the different Farmers involved in tomato production. Note that our segmentation does not overlap standard classifications, but is instead a more nuanced approach intended to help segment and identify target Farmers for the Postharvest Centers of Excellence.

Small Farmers

- < 0.25 ha of tomato cultivation; usually more focused on staple crops and own consumption crops; low quality production process and little use of intensification methods.

Medium Farmers

- 0.25 – 2 ha of tomato cultivation; focused on tomatoes and/or other horticulture crops rather than subsistence crops; likely to grow other horticulture crops; starting to practice intensive production (irrigation, crop rotation, use of inputs, etc.).

Large Farmers

- > 2 ha of tomatoes; very focused on cash crops and horticulture in general; definitely growing other horticulture crops; uses professional production practices and intensive production; may employ in-house technical help and agronomists. There are relatively few farmers with this profile, and most are located in the Eastern Province where farms are generally larger.

Companies

- Professional farming companies, incorporated. Own their land and heavily into tomato production (>5 ha) and also possibly working with out-growers. Professional practices and often greenhouse production. Very few of these companies exist in Rwanda.

Agriculture / Horticulture Cooperatives

- Formed by farmers and focused on either only tomatoes, or tomatoes and other market crops; often more production-oriented than market-oriented. Able to generate large volumes.

Specialty Cooperatives involved in tomato production

- Formed by non-farming groups (e.g. widows, HIV survivors, war vets) and focused on horticultural produce. Because they don’t have the skills in-house, they tend to hire more outside technical help than Farmer-supported coops, as well as more marketing support.

Farmer Associations (formal/informal)

- Less formalized than Farmer cooperatives, though sharing many characteristics.

=> There are many Farmers of tomatoes. The challenge for the Postharvest Centers and for other interventions in this space is targeting those Farmers that will benefit the most from interventions and training. The following evaluation is intended to lay the groundwork for that process.

FARMER EVALUATION

The above-mentioned Farmers have been evaluated on a number of metrics designed to assess their suitability for training and institutional support needs. The end goal is to identify those groups that are most likely to be receptive to and able to implement the training received or programs proposed.

	Small Farmers	Medium Farmers	Large Farmers	COMPANY	AG-CULTURE COOPS	"OTHER" COOPS	ASSOC
Access to Good Markets	L	M/H	H	H	H	H	M/H
Market Knowledge	L	M/H	H	H	M	M/H	L/M
Technical Knowledge	L	M/H	H	H	M	H	L/M
Business Savvy / Knowledge	L	L/M	M	M	L	L	L
Access to Finance	L	L	M/H	H	H	H	L
Access to Inputs	M	M	M/H	M/H	M	M	M
Govt Support	M	M	M	H	H	H	M/H
Postharvest Losses	H	H	M	M	H	M	M

Figure 3: Farmer Evaluation

L – Low; M – Medium; H - High

=> The aim is to decide on which segments to target, and then within that group identify those farmers that are open to new ideas and methods, and dedicated to their production. These groups will be ideal targets for the Postharvest Centers.

B. MARKET ACTORS AND SYSTEMS

MARKETING AND DISTRIBUTION MAP

The following provides an overview of different channels from the time the tomato leaves the field:

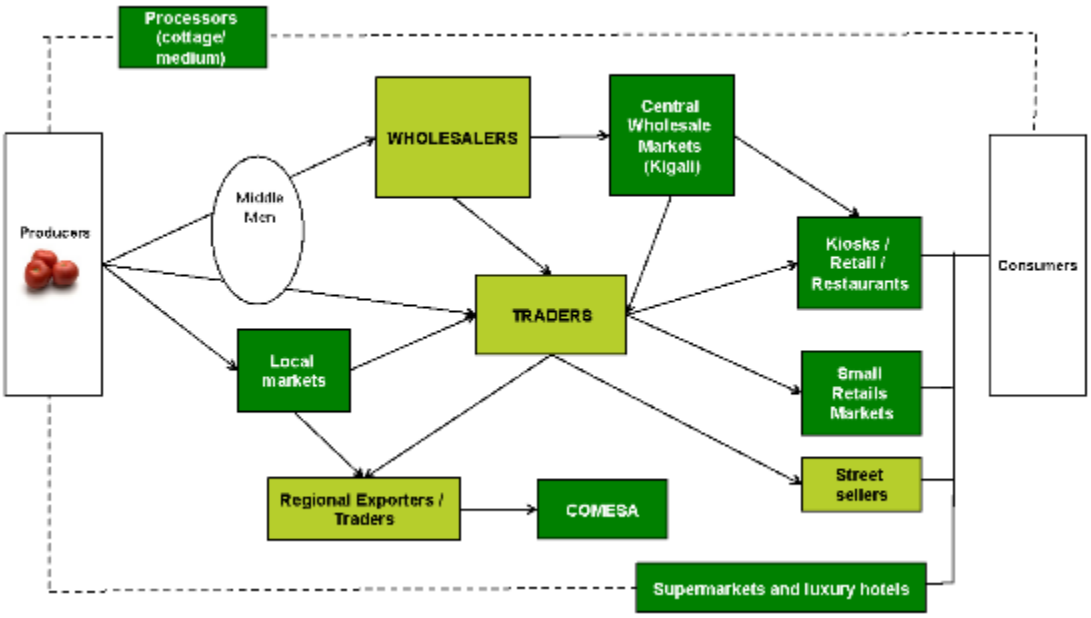


Figure 4: Marketing and Distribution Map – Tomatoes

OVERVIEW OF TOMATO MARKETING AND DISTRIBUTION ACTORS

Tomato Wholesalers

- Buy only from larger farms or at informal collection points; the EU study shows that 90% of co-operatives engaged in horticulture (note not specific to tomatoes) use this channel
- Extensive use of middlemen to identify harvesters and volumes
- May have their own truck or hire
- Employ limited sorting at the farm or collection level; all qualities are put into one basket (large 100 kg woven basket called *intebo*)
- Generally specialize only in tomatoes
- Don't tend to have regular customers (traders and retailers), though quality and price attracts repeat customers
- React opportunistically to price
- Generally profitable and don't hold much risk
- May be backwards integrated (i.e. have their own farms and supply source); an

estimated 30% of all traders (all agriculture crops) have their own farms[4]
- Will act as partners with preferred suppliers (i.e. high volume Farmers), even bringing them to wholesale markets to show them the system and increase transparency
- Tomato wholesalers have an association mostly for financial purposes (*Ikimina* associations)
- If large enough, will bring in produce from Uganda and Tanzania in low season
- Generally wholesalers are female, despite the long hours and potential dangers of the business

Middlemen

- Middlemen informally act as the conduit between smaller farmers, and traders and wholesalers: they negotiate prices, explain prices, act as facilitators, enforce informal contracts
- Business conducted almost entirely by phone
- Knowledgeable about tomato Farmers and production in their area: know who is harvesting what (quality), how much and when
- Paid by the truck driver (wholesaler) as well as by the farmer

Traders

- Buy from wholesalers and/or directly from farmers
- In purchase from wholesalers of "*intebo*" baskets, they bear the burden of risk as quality is not immediately apparent. Abuse is kept low in this non-transparent system only by relationships and trust
- Do the sorting into different qualities for sale to retailers; practice basic sorting and storage practices, such as rotation and airing
- Smaller baskets or basins are used to sort larger baskets into more consumer-oriented sizes
- Retailers can sell any quantity, but at lower prices throughout the day, as adjustments are made for degradation in quality. Their waste is low, but their losses are high
- Like wholesalers, many retailers tend to be female

The following is an overview of a typical wholesaler distribution channel, including prices:

[4] Sabine Abewe Hategekimana, Study on Regional Agribusiness Traders

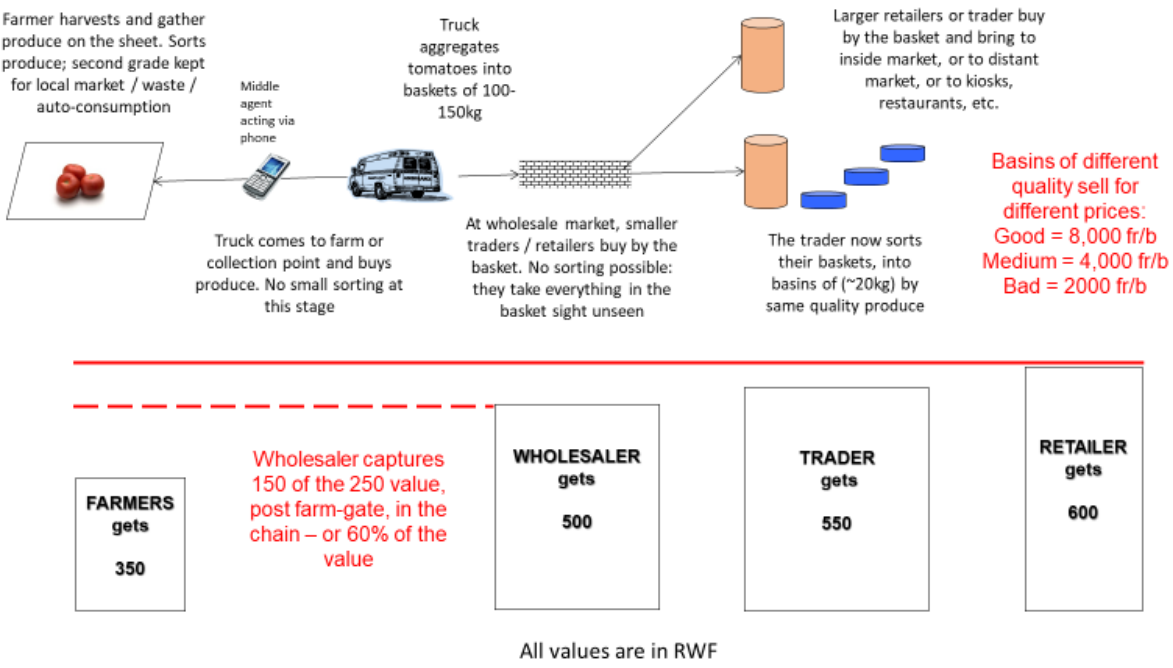


Figure 5: Wholesale Distribution Channel and Associated Value

Note that the price is just an assumption: good quality tomatoes, in off-season would be the 350 fr/kg farm gate value, and the trader's prices also reflect a specific seaso, and are shown here for comparison purposes only.

=> A key question for the Training Centers is if they want to incorporate and target these players in the chain (wholesalers, traders and middlemen) in addition to the Farmers?

FARMERS AS PART OF THE MARKETING AND DISTRUBUTION CHAIN

Small farmers may bring their produce directly to village markets or to informal collection points where they may sell to traders. They may also bring their produce directly to wholesale markets (especially those in the vicinity of Kigali). There they sell to retailers, traders or wholesalers who may be agglomerating for other markets.

Even if the farm is close to a market, in many cases farmers prefer to sell at farm-gate, even if it means a lower sales price. For most small-scale farmers, tomatoes are not their primary business – they have other crops to attend to – and travel includes cost and inconvenience, as well as time, and there is uncertainty of finding a buyer even if they make the journey.

Once sufficient volumes are aggregated, they can work more effectively with traders and wholesalers, either by selling their produce at the farm-gate or at a point close by.

C. MARKETS

END MARKETS

There are several end markets for tomatoes:

Local Markets – serving small villages and / or towns. The retailers in these markets generally buy directly from farmers or via small-scale traders. The prices in this market are significantly lower than in the wholesale markets in Kigali. They are generally open-air and have no cooling or storage facilities. Traders may buy from these markets for further sale in Kigali (depending on distance).

Daily spot wholesale markets, in Kigali – these are means by which the vast majority of tomatoes are sold in the Kigali area. Many of these wholesale markets operate outside of large retail markets, and finish their business before the retail market opens. Traders buy from these markets, and often sell to retailers within. Larger retailers may buy directly from wholesalers.

These markets, either at the wholesale or retail level, also serve as distribution points for smaller kiosks, shops, street sellers, etc., as well as to restaurants and end consumers.

Wholesale markets are open air (wholesale) or covered (retail), generally chaotic, have no cooling or sorting facilities, or washing facilities of any kind.

These markets are the only ones of any real significance for the small and medium-scale Farmer. Quality in these markets is determined by (in order):

- Size
- Redness
- Firmness
- The variety is not important (but it is, inasmuch as it impacts the above characteristics, especially size)

Niche high quality markets / International hotels and international high-end supermarkets
These are the highest paying markets, but also the most demanding in terms of quality, quantity, certifications, packaging requirements, etc. They favor large, professional farms or greenhouse Farmers.

These markets are very small (though will certainly increase in time), and are far from the reach

of the average small or medium-size open field farm. In order to upgrade to serve this market basically requires upgrading to greenhouse production and in some cases undergoing certification. As this is a longer-term strategy for the industry as a whole, it is currently out of scope of this study and the Postharvest Project.

Regional exports

Are only accessible by wholesalers and larger traders, and not directly by farmers themselves, though the study also found that traders from Congo and Uganda come to buy from (larger) farms during periods of surplus in Rwanda. Very limited data is available on this trade.

D. KEY TAKEAWAYS: MARKETING AND DISTRIBUTION

Tomato sales and distribution is a very fragmented system

- Traders and wholesalers play an integral part in the tomato industry
- Most are small scale with low levels of professionalism
- Just because the system appears small-scale and opportunistic does not mean it doesn't adhere to its own logic and market forces

The market rewards bigger players

- Larger Farmers have wholesalers and other buyers / retailers coming to their farms
- They command the best prices due to their volume and quality
- Smaller players do not attract or interest wholesalers or larger traders, and are stuck with village-level sales (poor market) or working with smaller traders serving those markets
- The focus for small farms should be on increasing production and / or pooling production in order to present the volumes required by the better channels

Aspirations of forward integration by Farmers must be balanced against the reality of Farmers

- Many lack appropriate transport
- Many lack of time and resources
- Small farms have other priorities than optimizing sales price

Preferred markets for smaller farms is wholesalers or larger traders

- Direct sales to higher end markets is outside the scope of this study.

Price fluctuations based on demand and supply imbalances are the key challenge for all players in the chain

Recommendations

The following interventions can be divided into two main categories: those that exist at an enabling environment or government level, and those that may be within the scope of this project and the Postharvest Centers. For example, the Postharvest Centers can include those interventions that are training or capacity building based; those that are collaborative, cluster building, and focused on facilitation and bringing Farmers together, and finally those that require only minimal investment in equipment or materials. We anticipate that not all will be under the scope of the project, and that one key activity will be prioritizing the interventions and developing a schedule for their implementation.

INPUTS & PRODUCTION - RECOMMENDATIONS

Government / Policy Level Interventions

- Move to a pharmacist model whereby sellers of inputs need some form of accreditation (light) to prescribe fertilizers, and especially pesticides
- Spread nurseries and seed farms to village level in horticulture-intense areas
- Extend government seed multiplication programs to horticulture
- Continue training to district-level agronomists in horticulture and / or develop system of roving dedicated agronomists, specialized in horticulture

Potential Project-Level Interventions

- Increase horticulture-specific awareness amongst accredited vendors and distributors of inputs, especially at the rural level
- Work with agriculture supply companies to identify horticulture-specific needs in seeds, pesticides and fertilizers and widen their range of products
- Encourage and form buyers' groups for input purchase
- Survey local agronomists about their horticulture knowledge and their desired training needs
- Work with RAB to develop more horticulture training programs
- Encourage and formalize purchasing groups for inputs and production equipment
- Work with small-scale Farmers to understand the barriers to use of government subsidy programs (irrigation, fertilizers, pesticides)
- Revisit greenhouse production as a priority
    - Promote greenhouse production using net houses for qualified groups, in a careful way and learning from mistakes of the past
- Improve information about tomato production. Several ideas include:
    - Advisory system via extension services for estimated tomato production
    - Improve MINAGRI statistics to break down bi-annual data from just "vegetables/fruits" into individual crops
- Raise awareness with banks and financing institutions about horticulture investments, risks and the industry in general

HARVEST AND POST HARVEST RECOMMENDATIONS

Government and Policy-Level Interventions

- Similar to the plastic bag ban, consider and carry out feasibility study for the banning of bags and sacks and the implementation of crates for targeted number of agricultural crops and commodities, including tomatoes.
- Continued government support for *Ubudehe* program targeting improvement of small and secondary roads
- Continue support for development of local packaging industry

Potential Project-Level Interventions

- Training on harvest and postharvest best practices, both at the Training Center and via partnerships with village-level extension services
- In-depth investigation of the barriers to use for collection centers, including determination of maximum distance to travel vs. volume collected
    - Investigate innovative transport solutions to increase use of potential collection centers and / or expand access to better markets, eg. leasing subsidies for bikes or scooters.
- Support the formation of purchasing groups for harvest and postharvest equipment
- Development of and support for on-farm, localized cooling and storage solutions

MARKETING & DISTRIBUTION

Government and Policy-Level Interventions

- Build extension service capacities to relay market information and market access information
    - Emphasis on helping Farmers research the market and marketing options *before* planting
- Support land consolidation schemes, informal farmer associations and collaboration efforts in order to increase volumes and yields
- Support development of the Kigali Wholesale Market project and ensure that small farmer needs and requirements are incorporated as much as possible
- Migrate and extend e-SOKO system by developing mobile applications for use on cell phones

Potential Project-Level Interventions

- Support all production and postharvest efforts to increase yield and therefore volume
- Business training for horticulture farmers (expanded upon below in C – CAPACITY

BUILDING)
- Support and training for professionalization of the fragmented system, by working with both Farmers and wholesalers / retailers
- Support and training for wholesalers and retailers engaged in the tomato sector

PROCESSING RECOMMENDATIONS

Government and Policy-Level Interventions

- Continue support for development of local packaging industry

Potential Project-Level Interventions

- Conduct detailed study on tomato processing options, including financials for various types of industrial production (ketchup, pastes) and investigate the dried tomato industry, as well as cottage industry products (jams, juices)
- Incorporate potential investors in this space in the PostHarvest Training Centers' activities

FARMER BUSINESS CAPACITY BUILDING INTERVENTIONS

The focus of the Training Centers will be on technical postharvest training, addressing the issues outlined above, but given that horticulture is a risky, fast moving commercial sector, Farmers will also benefit from business skills and entrepreneurial training. Once core target groups are identified, training needs and programs can be developed that target horticulture Farmers in general, and tomato Farmers specifically.

In order to increase Farmers' business skills and give them more of a marketing mindset, crucial for success in horticulture, training programs including the following subject matter could be developed by the Postharvest Training Centers:

- Understanding price fluctuations and demand and supply
- Understanding value chains and pricing
- Dealing with traders and marketing agents
- Developing farm calendars and operational plans
- Benefits of collaboration and clustering, for purchasing and increasing industry power
- Finances: Calculating profit and loss and tracking expenses
- Production planning and harvesting scheduling
- Accessing support and resources
- Further processing and value addition
- Strategic thinking and long-term planning
- Legalities and contract review

4. COMMODITY SYSTEMS ASSESSMENT

Methodology

The Commodity Systems Assessment (CSAM) is a step-by-step methodology for describing and evaluating the planning, production, postharvest handling and marketing of agricultural commodities. The modified CSAM (Lagra, Kitinoja and Alpizar, 2016) includes interviews of stakeholders, observations of handling practices, and direct measurements of quality and quantity losses on farm and at the wholesale and retail market levels. The field based measurements at the farm, wholesale and retail markets have increased the knowledge base and helped to identify priority postharvest problems that currently limit market access for small farms and rural marketers. Results from the rapid assessment provides input that we can use to promote technology awareness, adoption and utilization, as well as answer key research questions to inform the project.

The CSAM report includes:

- the average and range of postharvest losses
- losses segregated by category (physical injury, pathological disease, insect damage, water loss, other) at each stage in the postharvest value chain
- the estimated loss of market value for the crop
- recommendations for reducing postharvest losses

The districts that were included in the CSAM study include: Kigali, Nyagatare, Muhanga, Nyabugogo, Nyarugenge and Bugesera. District headquarters are shown on the map below.

The goal of the assessment was to sample postharvest losses for a random selection of 10 farms and 10 markets (collection points, wholesale and retail marketplaces) via direct measurements and observations. In total 32 people were interviewed including 4 from agrochemical sector, 1 agronomist, 8 tomato farmers, 16 tomato retailers and 3 tomato wholesalers. Interviews and observations identified several key issues, including use of poor quality seeds, poor production practices, lack of training for workers and use of inappropriate practices (food safety issues).

CSAM data collection methods and protocols

CSAM is a systematic process of using surveys, interviews and observations to collect data on the key aspects of the value chain, including production, postharvest handling and marketing. It considers the entire commodity system, from planning and production to processing and marketing, but we will focus more on the postharvest and marketing aspects trying to

determine the relative costs of any potential or observed changes in handling, containers, value addition or marketing practices.

A complete CSAM, collects data at 26 points, along the value chain, as shown in the image below.

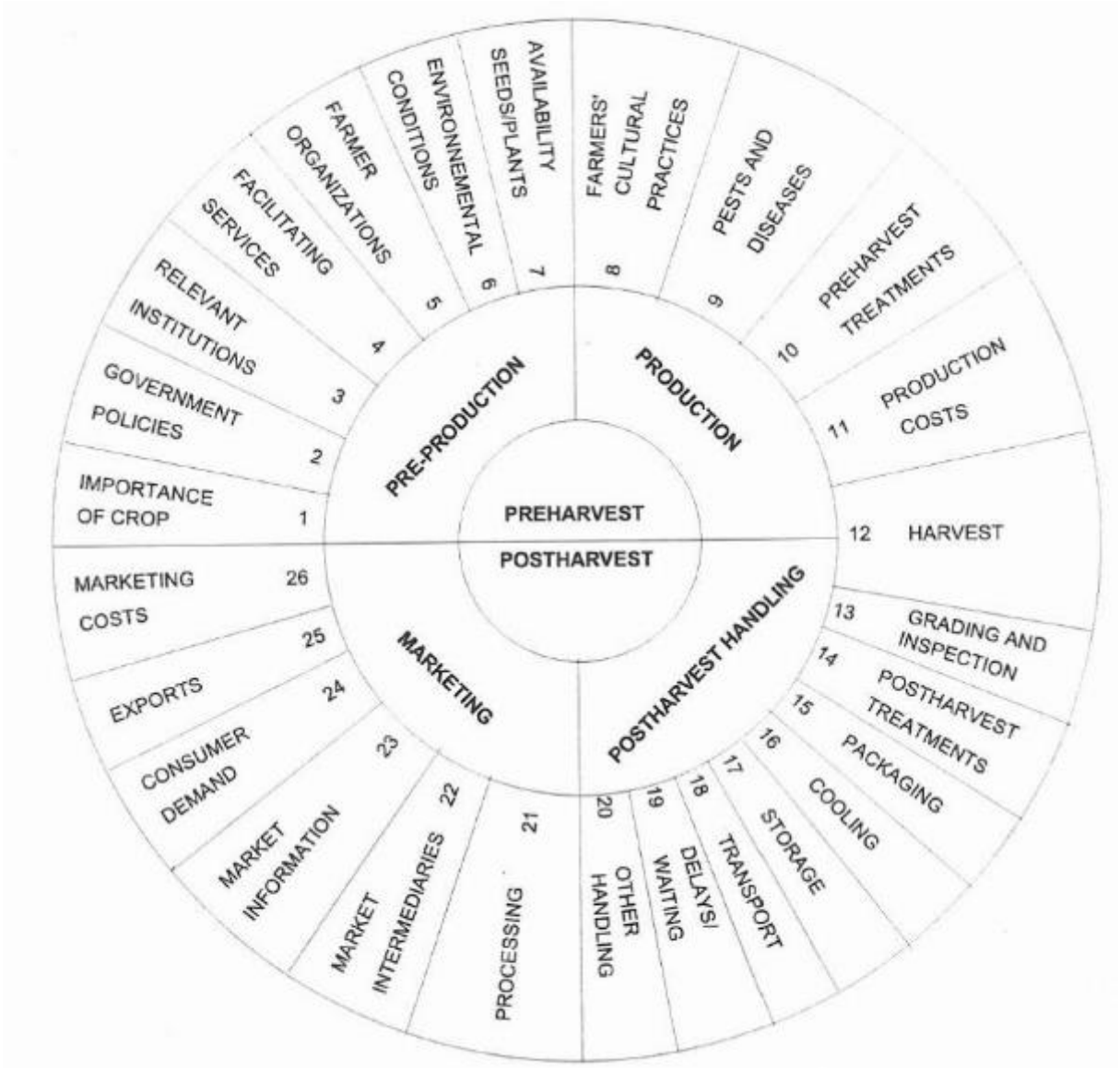


Figure 6: Principal components of a CSAM (LaGra 1990)

Data on the tomato value chain in Rwanda was collected via interviews following a set of written questions (Annex1A), observation, and field measurements. Questions related to

production were asked mainly to farmers; marketers were asked about postharvest handling and marketing, and researchers, project staff and/or extension workers were asked about the entire system. Published articles, unpublished documents, and review articles were also used as sources of information to complete this report.

Additionally, there are worksheets used for on-farm (Annex 1B), packinghouse/ collection center (Annex 1C), wholesale (Annex 1D) and retail market (Annex 1E) data collection on postharvest losses, quality characteristics, market value changes, general shelf life, and a worksheet on the costs/benefits of potential changes in practices (Annex 1F). The protocols for using the data collection worksheets are included in Annex 1G.

Results from these rapid assessments provided input we can use to promote technology awareness, adoption and utilization, as well as answer key research questions to inform the project.

Tools used to measure losses

CSAM team members visited the field carrying with them a set of tools that helped them measure different parameters that assess quality and losses. (Annex 1G)

- Scales to assess the weight loss caused by postharvest practices
- Cameras to report the quality of the crop and handling practices at any segment of the value chain
- Digital thermometer (temperature probe) to measure the temperature and the relative humidity of the environment at the time of the visit and the temperature of the tomatoes
- A refractometer to record the solid solubles content (SSC%)
- Quality rating scales and color charts (maturity indices).

Site selection for the Tomatoes CSAM study

The team surveyed the country and identified and labeled attributes to the principal growing areas for open field tomatoes. The greenhouse industry was not included as it is a very, very small percentage of the total production of tomatoes in Rwanda.

The process was as follows:

1. The areas of tomato production were categorized as: Irrigated scheme, Marshland, or Rainfed (dry/wet)
2. The typical production areas were identified. These included areas that were

representative of the Rwanda domestic trade. (A few areas next to the borders sold to the neighboring countries, receiving different prices, having different logistics, etc. – these were not included in the study.)

3. The major postharvest chain points from farm to retail were identified, with those representing the greatest percentage of postharvest losses targeted for study.

At the **farm level**, the more representative stakeholders in the open field tomato farms were identified as:

- 25% Small scale with 0.1-0.2 ha/farmer
- 15% Irrigated land (Consolidated land) with 0.25 ha/farmer
- 60% Cooperative farmers with 0.5 ha/farmer

At "**Wholesale pick up" Point/Collection point/Aggregation point**. This point is just a place without infrastructure located nearby farming places. Small-scale farmers or groups take their produce to the pick-up point that is usually located 1 to 3 km from the farming area. Crops are handled in baskets with a capacity of 10-20kg. Transportation to this point is by bicycle or foot.

At the **Wholesale market:** Wholesalers take produce from: Regional and Local markets. Capacity of trucks used: Short: 5T-7T, Long: 12T. Wholesale market is the space where traders can take produce for local sales. Generally wholesalers are the only ones having trucks for transportation (90%).

At the Retail marketing level: Retailers buy a small portion about 20-50kg packaged in 1 to 3 baskets. Hotels, restaurants, supermarkets and institutions are considered as retailers and they buy crops from wholesalers. Kimisagara Market is one of the major Retail Markets in Kigali. Retailers are classified into 3 major types, namely ambulatory retailers; retailers stationed outside wholesale markets and boutiques all over the country.

Retail markets are divided into the following categories:

1. Ambulatory: Mobile, walking through the market (with produce on cart or on their head) or along the roadside (retailers hold from 5kg to 10kg of produce composed of 4-5 types of produce such as cabbage, fruits, tomatoes and fresh beans.
2. Retailers stationed outside the wholesale market (they do not pay taxes)
3. Boutique: small stores toward the city having crops with value around 1,000,000 Rwf annual turnover and they transport produce by motorcycle, bicycle or shared pickups (potential capacity: 100-200 kg/day)

The districts that were included in the CSAM study include: Kigali, Nyagatare, Muhanga,

Nyabugogo, Nyarugenge and Bugesera.

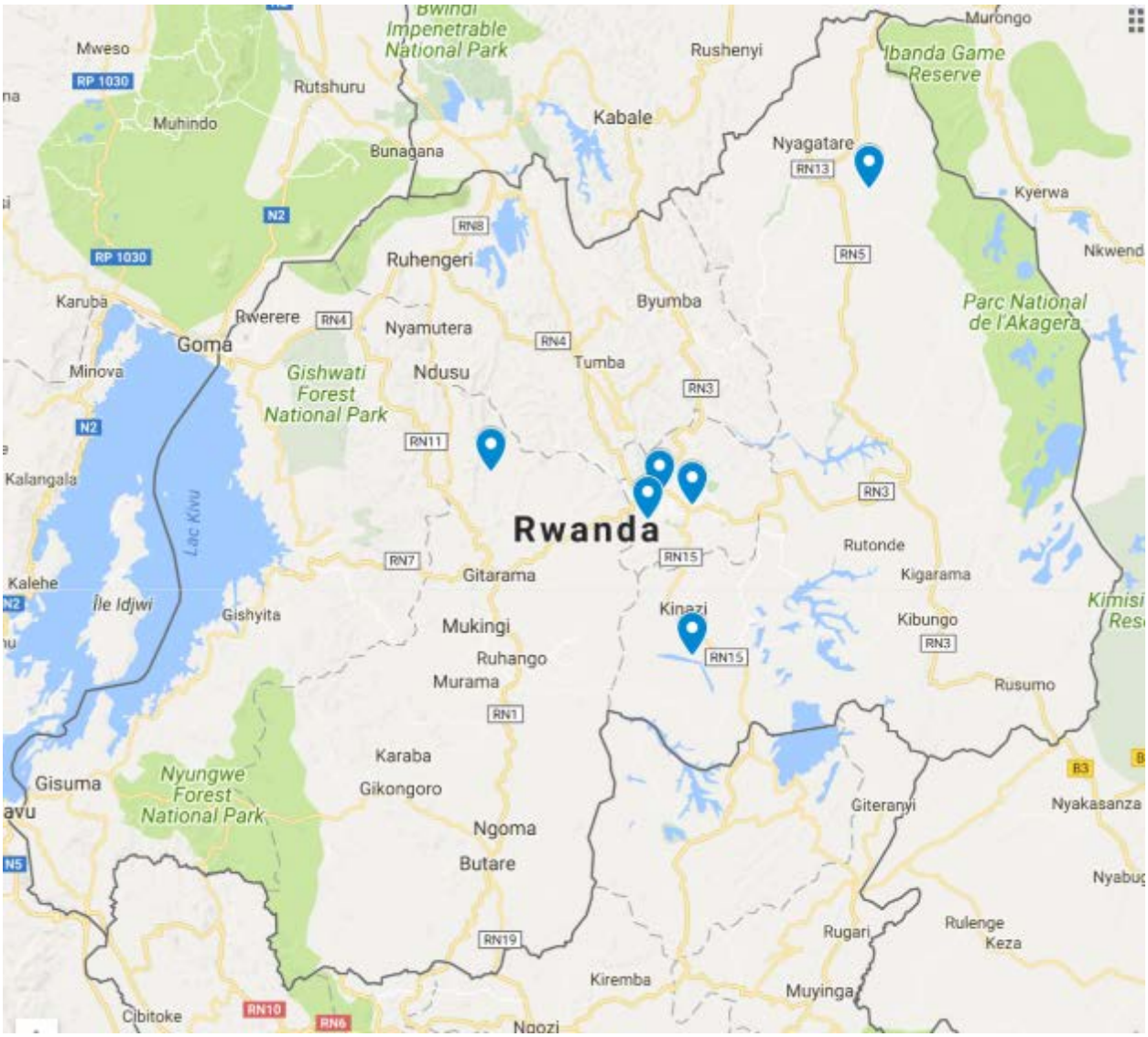


Figure 7: Districts included in the CSAM tomato study

Findings

The following is a summary of the major findings for the crop. Interviews and observations identified several key issues, including use of poor quality seeds, poor production practices, lack of training for workers and use of inappropriate practices (food safety issues).

There were six major reasons for high postharvest losses for tomatoes in Rwanda**:**

1. **Over-maturity at harvest** -Tomatoes are over-ripe and already soft when harvested at full-red stage.

2. **Rough handling during harvest** – Those interviewed during the CSAM process described how, along the whole value chain, the laborers (farm family members or hired help) are not trained to handle the produce well. The pickers pluck the tomatoes from the plant in a way that sometimes leaves the tomato and the plant damaged. Tomatoes are tossed into the containers. Farmers register losses on the farm itself, because of damage from sunburn, fungal damage and mechanical. Often times, tomatoes that are harvested at red-pink stage are discarded, as farmers believe that consumers want red-ripe tomatoes.

3. **Poor postharvest handling practices** - Tomatoes are squashed on the ground by the feet of the pickers because of insufficient spacing. Tomatoes are also harvested in plastic buckets that are stacked one on top of the other as shown in the picture below – this causes crushing and bruising of the fruit during headload transportation from the field. This is also a food safety concern. It was also observed that the produce was being handled multiple times before it reached the collection point. Without much consideration tomatoes are poured, dumped or thrown from one container to another, on farm and at wholesale pickup points. Quite a lot of tomatoes are stepped on in the farm, at the packing area and on the truck.

4. Poor quality containers

Farm: On the farm during harvest, small plastic baskets that are smooth inside and not vented are used.

Wholesale: Then the tomatoes are packed into either plastic sacks or woven wooden/stick baskets at the wholesale level. The plastic sacks are usually lined with dried banana leaves or grasses for protection. The plastic sacks have a capacity of 35 kg and are stacked one on top of the other. The woven stick baskets are estimated to be 200 kgs but can be anywhere from 110 to 140 kgs. The baskets are rough and cause bruising and pricking where it touches the tomatoes.

Small-scale traders – Small-scale traders use bicycles to transport tomatoes from the farm to the markets and use small buckets which have 20 kg capacity. These buckets are often smeared with cow dung to increase durability, which is a food safety concern.

5. Rough transportation

Smallholder farmers have limited transportation resources and rely on middlemen to buy tomatoes and transport them to the markets in Kigali. Average price of transporting 1 kg is 10-15 RWF or 100,000 RWF for 10 tonnes. Tomatoes transported by truck are packed into the woven baskets or the plastic sacks, and trucks can have a capacity from 0.75 tones (small pick-up) to 7 tonnes (Mitsubishi trucks). Time to Kigali can take up to 3 hours and 9 hours to Gisenyi.

Tomato plastic sacks and baskets are both stacked one on top of the other, which causes damage during transportation. Farmers also have to face delays for pick-up. Trucks do not come

on a daily basis, so tomatoes may stay at ambient temperatures for 3-4 days. Delays may also happen because of rain.

6. Lack of temperature management - Farmers are not familiar with cooling and do not transport the picked fruit to shade immediately. There are no on-farm cooling facilities and tomatoes are exposed to direct sunlight. After harvesting, the tomatoes are often covered with banana leaves to reduce the heat. There are no cooling or shad structures in place and sometimes farmers use tree shade. Packing the tomatoes with banana leaves also does not offer ventilation during transportation which can take from 3 to 9 hours (depending on location).

The main observations by CSAM component are highlighted below.

Table 2: CSAM Findings Summary - Causes and Sources of Losses for Tomatoes in Rwanda

CSAM Components	Interviews	Observations	Recommendations
PLANNING/ PRE-PRODUCTION	• Poor quality seeds, farmer saved for many generations		• Use of improved seeds
PRODUCTION		• Plants sprawling in fields during harvest • Pickers stepping on plants and fruits, ripe fruits left where they have fallen on the soil	• Trellising to increase yields and reduce damage
POSTHARVEST	• Poorly trained field workers • Buyers/traders demand use of pesticide sprays right before the harvest (misunderstand its purpose, widely believe Mancozeb enhances ripening uniformity)	• Fruits are harvested when full red ripe, very soft • Many handling steps, many exchanges, excessive handling • Filled field containers are stacked 3 or 4 high (compression damage) • Enormous containers do not provide protection during transport (large sacks, huge baskets) • No cooling • Little or no processing	• Use of maturity indices to identify breaker stage fruits for harvesting (with longer shelf life) • Field packing to reduce handling damage • Gentle handling • Use of smaller, more protective containers • Use of proper "postharvest intervals" when using pesticides • Use of shade during delays • Improve options for small scale processing businesses (dried tomatoes, powders, sauces, ketchup, salsas, chutneys, etc)
MARKETING	• Wholesalers pay a 35% discounted price/kg due to expected damage and losses	• Exposure to sun • Rough handling	• Use of shade • Gentle handling

The Journey from Farm to Market

The size of the tomato farms included in the sample for data collection measurements ranged from 2 to 15 hectares (average size 7.8 ha). The range for the distance to market was 34 to 138 km (average distance = 94.1 km). The data collected on farms was either during or within 2 hours of the harvest (7 cases) or 4 to 5 hours after the harvest (3 cases). In only one case, the data was collected 3 days after the harvest.

Most of the fruits moved through a local or regional "wholesale pickup point" or collection center, which were outdoor areas located near a major road but without any formal packing facilities.

Quality characteristics such as ripeness and firmness were measured on the farm and in the marketplaces, and were determined to be related to generally high levels of postharvest losses. The baskets used for tomato transport are huge. The traders do not weigh the wholesale woven baskets, they just estimate and take the basket as equal to 100 kg. After weighing different baskets, the CSAM team determined that the full woven basket is between 90-140 kg.

Table 3: Quality characteristics for tomatoes in Rwanda

Location	Relative perishability *	N	Air Temp	Pulp Temp	Protection provided by packaging **	Soluble Solids Content %	Firmness
Farm	3	11	25C	28C	2.5	4.1	2.4
Collection point	3	6	29.1	30	2.6	4.5	2.5
Wholesale market	5	2	24.1	27	3.0	4.6	1.0
Retail market	5	14	27.3	26.9	2.3	4.4	2.5

* 1=low, 3=moderate, 5=highly perishable (red ripe)

** 1= low, 3 = moderate, 5 = excellent protection

Firmness rating: 5=hard to 1= very soft

Postharvest losses for tomatoes

The measurements of percent discards, defects, decay and mechanical damage for tomatoes in

Rwanda are summarized in Table 4. Damage and defects were extremely high and generally resulted in a lower sales price rather than as discarded produce. Only the very worst quality, inedible produce was discarded.

Table 4: Percent Postharvest losses for tomatoes in Rwanda

Location	Avg Time from harvest	Ripeness	% defects	% decay	% mechanical damage	% sorted out/ discarded before sale
Farm	2 hours	62% red 35% light-red	65%	40%	33%	21.0% Range: 5 to 40%
Collection point	4 hours	77% red 22% light-red	47%	32%	37%	11.5% (one sample)
Wholesale market	N.A.	57% red 42% light-red	62%	42%	80%	10% (one sample)
Retail market	30 hours	70% red 23% light-red	70%	31%	68%	13.6% Range:4.5 to 20%

These findings are similar to those reported for tomatoes in Rwanda during past assessments (WFLO 2010; Kitinoja and Alhassan 2012; van Dijk et al 2015; Kitinoja and Kader 2015). Mechanical damage is extremely high due to rough handling and the use of poor quality containers. Mechanical damage is known to affect flavor, as bruising is related to the development of off-flavors (Kader 1986). Fully ripened tomatoes are very susceptible to mechanical injuries during harvesting, resulting in shorter shelf life (Toivonen 2008).

Estimated value of postharvest losses

The damage observed in the farm during harvest by the CSAM team was enormous (ranging from 20 to 60%). The market value of the tomato crop decreased as the quality decreased, leaving a wide opening for improved postharvest handling and investment in improved containers. Excellent quality tomatoes could be sold for 350 to 500 Rwf per kg. One example from Nyabugogo, Rwanda (October 2016): soft fruits = 200Rwf/kg; damaged/broken fruits = 100Rwf/kg.

If the annual production of tomatoes is 154,000 tonnes, this **equates to a loss in market value of $US18.5 to $77 million per year (20-60%)**.

Table 5: Estimated range of the value of postharvest losses of tomatoes in Rwanda for 154,000 tonnes of produce (annual production in 2014)

	Market value range (high quality)	Market value range (low quality)	Range of Annual economic loss in Rwf	Range of Annual economic loss in $US
Price per kg (RWF/kg)	350 to 500	100 to 200		
Total market value	53.9 trillion Rwf to 77 trillion Rwf	15.4 trillion Rwf to 30.8 trillion Rwf	23.1 trillion Rwf to 61.6 trillion Rwf	$18.5 million to $77 million

800 RWF = USD 1

At the wholesale market level, the estimated loss reported by traders and sellers was 35% (expected losses). At the Nyabugogo market, the wholesale buyer was responsible for the loss, but in the cases where fruit damage was higher than normally expected, the woven wholesale basket is singled out and the loss must be covered by the Farmer by reducing the normal price.

Costs and benefits of improved postharvest practices for tomatoes

The first example is for use of maturity indices during the harvesting. Using a color chart to harvest at the turning stage, with firm fruits that will turn to red within 3 or 4 days, thus reaching the market with least mechanical injury generates an immediate increased profit of $170 for each 1000 kg load.

Table 6: Cost Benefit Analysis: Use of maturity indices for tomato harvesting

Start with 1000kg	Current Practice	New Practice
	Harvest at light-red to full red ripe, soft fruits	Harvest at turning stage, firm fruits, turning to red within 3 or 4 days
COST		
Color charts for training on maturity indices		4000 Rwf ($5)
BENEFITS		
% Loss	30%	10%
Amount to sell	700 kg	900kg
Value per kg	200 Rwf ($0.25)	400 Rwf ($0.50)
Total market value	140,000 Rwf ($175)	280,000 Rwf ($350)
Market value - costs	$175	$345
Relative profits		+ $170
ROI		Generates an immediate increased profit of $170 for each 1000 kg load.

The second cost/benefit example is for the use of shade to protect the tomato fruits during delays or marketing. Keeping produce in the shade can help to reduce pulp temperature by 10 to 15°C. For small scale farmers, this shade structure is simple and affordable technology. It will return its cost after 5 use only. Each subsequent use generates an additional $10 per load of 100kg.

Table 7: Cost Benefit Analysis: Use of shade for harvested tomatoes in Rwanda

Start with 100kg	Current Practice	New Practice
	Leaving piles or containers of tomatoes in the direct sun	Use of shade to provide lower temperature for produce during delays or marketing
COST		
Simple shade structure, portable	No cost	$US 50
BENEFITS		
% Loss	30%	10%
Amount to sell	70 kg	90 kg
Value per kg (excellent quality)	$0.50 (400 Rwf)	$0.50 (400 Rwf)

Total market value	$35.00	$45.00
Relative profits		+ 10.00
ROI		5 uses fully pays for the shade structure, each subsequent use generates an additional $10 per load of 100kg.

Two examples are provided for use of improved containers.

Replacing the very large baskets used in transport of tomatoes to market with plastic crates (smooth on the inside surfaces and vented on the sides) will prevent damage during packing and transportation and allow tomatoes to have good ventilation during delays and marketing. These crates are also stackable so they prevent compression damage. This simple technology will reduce the losses by from 30% to 10% and increase the earnings of the farmer/trader. Only 10 uses will fully pay the plastic crates, subsequent uses will generate an additional $9 per load of 100kg.

Table 8: Cost Benefit Analysis: Use of traditional 100kg baskets versus plastic crates from farm to market

Start with 100kg	Current Practice	New Practice
	Large 100kg baskets used in transport of tomatoes to market: bruised and damaged during packaging, transportation, marketing suffer from decay	Plastic crates smooth inside surfaces and vented sides prevent damage and allow tomatoes to have good ventilation
COST		
10 plastic crates shallow size for delicate crops ($US 9 per piece)	No cost (reuse enormous, old baskets many times)	$US 90
BENEFITS		
% Loss	30%	10%
Amount to sell	70 kg	90kg
Value per kg (excellent quality)	$0.45 (500 Rwf)	$0.45 (500 Rwf)
Total market value	$31.50	$40.50
Relative profits		+ 9.00

ROI		10 uses fully pays for the plastic crates, subsequent uses generate an additional $9 per load of 100kg.

Replacing the huge woven sacks (100 kg(used in transport of tomatoes to market with plastic crates (smooth on the inside surfaces and vented on the sides) will prevent damage during packing and transportation and allow tomatoes to have good ventilation during delays and marketing. This simple technology and will reduce the losses from 30% to 10%. The investment in crates will be fully repaid with only 3 uses, and subsequent uses will generate an additional 220,000 Rwf per load of 1000kg.

Table 9: Cost Benefit Analysis: Traditional gunny sacks versus plastic crates for transport to market

Start with 1000kg	Current Practice	New Practice
	Huge woven sacks used in transport: tomatoes are bruised and damaged during packaging, transportation, marketing, suffer from decay	Plastic crates smooth inside surfaces and vented sides prevent damage and allow tomatoes to have good ventilation
COST		
Large sacks (34 @ 200Rwf)	6800 Rwf	
100 plastic crates shallow size for delicate crops ($US 9 per piece or 6500 Rwf)		$US 900 or 650,000 Rwf
BENEFITS		
% Loss	40%	3%
Amount to sell	600 kg	970 kg
Value per kg	200 Rwf (poor quality)	350 Rwf (very good quality)
Total market value	120,000 Rwf	339,500 Rwf
Relative profits		+ 219,000 Rwf ($US 275)
ROI		3 uses fully pays for the plastic crates, subsequent uses generate an additional 220,000 Rwf per load of 1000kg.

Recommendations

1) Training of trainers (capacity building) in improved tomato handling on the farm:
Leaders of cooperatives involved in tomato production should be trained in harvest indices, postharvest handling, use of improved containers, sorting/grading, use of shade.

2) Training on safe chemical use: Training of the cooperative members, individual farmers as well as buyers and traders is recommended on safe agricultural practices which include pesticides control methods. If any chemicals are applied, the farmers should be trained on PHI (post-harvest intervals) for chemicals to adhere to standards for the amount of residue levels allowed on the tomatoes harvested for consumption.

3) Demonstrations that are recommended for the Postharvest Training and Services Centers on cost effective practices for reducing postharvest losses in tomatoes include:

- Maturity indices, quality and shelf life
- Use of shade (various types of simple, low cost structures and portable shade such as market umbrellas)
- Use of improved containers for transport and marketing (smaller sizes, stackable baskets, plastic crates)
- Zero Energy Cool Chamber (brick and sand, 100 kg capacity) for temporary cool storage
- Small-scale tomato processing methods (solar drying, sauce making, juices)

4) Recommended postharvest technologies

- Evaporative cooling systems - There is a need for cooling facilities put in place at the farmer's collection points to reduce losses of moisture and to keep the tomatoe temperatures low until the time that they reach the consumers. If there are reliable cool chain facilities which have regulated temperatures that are favorable for fresh tomatoes and also which is closely monitored starting from the evaporative cooling system at the collection points to the cold store trucks there would be limited loss of tomatoes. Introduction of evaporative cooling system will greatly reduce losses of produce at the collection centers as most of the produce of tomatoes will have a longer shelf-life from picking time. A Zero Energy Cool Chamber (ZECC) that doesn't require any power to operate can keep the produce stored in the chamber cool. These technologies and several other cold chain management options have been fully described in Kitinoja (2013), Kitinoja and Thompson (2008) and Winrock (2009).
- Plastic crates - Materials used in harvesting of tomatoes which include crates, basins, woven baskets, plastic gunny sacks are not protective enough and may be unclean to handle harvested tomatoes. The introduction of reusable plastic crates in the supply chain

of tomatoes requires a closed system to prevent loss, damage and theft. This needs an active management system put in place for managing and control of crates, which could be supported and funded by partners in the tomato supply chain, including transporters, suppliers, traders, and customers. The system should be a reliable system to audit all crates in circulation, the crates chosen should be crates that can easily be stacked and fitting well to ease transportation and easy to move from one point to another they need to have strong handles to carry. Packaging and transport of tomatoes in plastic crates that are aerated and can be properly stacked, potentially in combination with insulation materials, will be a durable solution to reduce losses in the value chain. Postharvest Education Foundation (PEF) published a White Paper on the use of returnable plastic crates (Kitinoja 2013) which can be used as a training guide.

- Processing and packaging - Processing and packaging of tomatoes is at its initial stage and is having challenges due to competition from imports of similar products like ketchup. There is a need to get more investors in the processing and packaging industry to cover the losses experienced at the high season of tomatoes that comes during October - November. The farmers will need to provide a continuous high quality supply to the industry in order for the industry to be sustainable.

5) Postharvest agri-business opportunities for tomatoes should be promoted.
These include:

- Trader/grower partnerships, where improved tomato production, harvest practices and postharvest handling on the farm leads to increased profits for both the growers and the traders.
- Local manufacture of tomato paste, sauces and juices (with flavors, package sizes and prices targeted to local consumer preferences).

Table 10: Identification of research needs for tomatoes in Rwanda

No	Research	Comments on what was observed/reported in surveys
1	Microorganism and mycotoxins contamination	The majority of open field tomatoes in Nyagatare districts showed fungal and bacterial rots.
2	Diseases in Tomatoes cultivated in Rwempasha sector	Farmers from Rwempesha in Nyagatare district were claiming about the diseases which devastate their tomatoes. For this reason, some farmers have planned to move from this place to another one called Kagitumba located in Nyagatare district.
3	Market research: Quality (nutritional, cooking, sensory, physical damage and storage stability characteristics) of ripening tomatoes	There is not yet any market demand for light-red, pink, turning, or breaker colored tomatoes. This may be due to lack of information on good quality of ripening tomatoes. Only red colored tomatoes were found for sale at regional and local markets.
4	Design and development of improved Rwandan containers for open field tomatoes (comparative studies)	Tomatoes are harvested in bowls/plastic basins, gunny sacks, or small woven stick baskets which are locally fabricated. They are transported and stored in large woven stick baskets and in gunny sacks. These containers poorly protect or damage the tomatoes. They do not provide enough ventilation for the tomatoes. Farmers and sellers are afraid of the high cost and irregular supply of imported containers (if any are available).

The following are provided as guidance for reducing tomato losses in Rwanda

Table 11: Identification of training needs for reducing postharvest losses

No	Training Needs	Comments on what was observed/reported in surveys	Target group
1	Spacing or staking plants	Pickers step on tomatoes when they harvest due to lack of enough space to walk in the field.	Farmer/RAB/MINAGRI
2	Gentle handling	Pickers drop tomatoes in the containers in the way that damages tomatoes	Farmer/ picker

3	Adaptation of cool chain, beginning with early morning harvesting, use of shade	Harvested tomatoes stay long under sunlight during picking, packing, transport and selling.	Farmer/ transporter/ seller/consumer/RAB/NAEB/MINAGRI/MINICOM/Public and private investors
4	Sale by grading/sorting	Harvesters and wholesalers do not sort into different grades. Good and poor quality tomatoes are mixed together and sold together.	Farmer/Harvester/wholesaler/ NAEB/MINAGRI/MINICOM/Public and private investors
5	Sale by weight	Farmers, wholesalers and most of retailers do not sell tomatoes by weight, just by volume/whole container. Farmers, sellers and consumers are all unaware of the real price/kg.	Farmer/seller/consumer/ MINICOM/Public and private investors
6	Harvesting and consumption of ripening tomatoes	Only red colored tomatoes are found at the collection points, packing centers, and markets. This may be to the lack of enough information and training to farmers, harvesters, sellers and consumers on good quality that light-red, pink, turning and breaker colored tomatoes have. Red tomatoes are much more susceptible to damage than pink or ripening tomatoes.	Farmer/harvester/seller/ consumer/ RAB/NAEB/MINAGRI/MINICOM/ Public and private investors
7	Utilization of strongly protective and ventilated containers	Rough handling causes a lot of damage to tomatoes. The currently used containers do not offer enough protection and ventilation and can mechanically damage tomatoes (rough interiors, too large).	Farmer/harvester/seller/NAEB/ MINAGRI/MINICOM/ Public and private investors

Advocacy issues affecting the postharvest losses of tomatoes

The following are advocacy issues for reducing postharvest losses of tomatoes in Rwanda:

- Increase access to improved varieties of tomatoes (pest resistant, high quality fresh market, plus varieties for processing)
- Improve rural roads to reduce delays and minimize rough transport
- Promote the manufacture of plastic crates in Rwanda
- Provide more support for extension/outreach in postharvest "best practices"
- Promotion and investment in a cool chain for postharvest handling, storage and transport of perishable foods

The planned "Kigali Wholesale Fruit & Vegetable Market" (a NAEB project) aims to develop a professional horticulture wholesale market with quality standards and good sanitation/hygiene.


KINAZI
KINAZI

5. LIFE CYCLE ASSESSMENT

Methodology

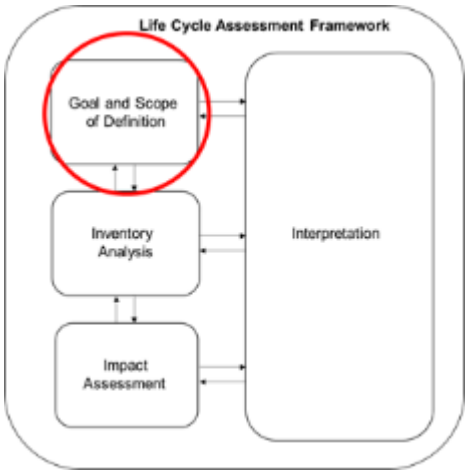
Postharvest losses occur across the value chain for all crops in all economies, however, in Rwanda there are particularly high postharvest losses. These losses directly reduce the final yield of the saleable and consumable product. Reduced product yield translates to more land, water, fertilizers, chemicals, and other inputs per kg or mass of final product sold to a consumer. Reducing postharvest losses is key to reducing the environmental impacts of agriculture products and conserving the limited resources in Rwanda.

The spoiling of food creates environmental impacts in multiple ways. First, the resources and energy required to make food is greatly increased on a per pound consumed basis when much of the food fails to successfully reach the market. To maximize farm resource use efficiency, decreasing postharvest waste is the largest environmental lever. In addition to increasing the efficiency of our resource use on the farm level, by decreasing food waste, the energy and resources used to bring the food to market will not be wasted on spoiled food. Furthermore, wastes associated with spoiled food will be reduced which lowers the environmental impacts of decomposing food and resources required to dispose of this food waste. The environmental sustainability analysis will focus on fossil fuel use and greenhouse gas (GHG) emissions associated with the crop value chain. The environmental hotspots, or stages after harvest that create the most environmental impacts, will be identified. GHG emission and energy use associated with new postharvest practices resulting from this work will be determined and compared to the business as usual values. This will ensure that postharvest improvements will also benefit the environment and will help ensure a sustainable and more prosperous future for the people of Rwanda.

Life Cycle Assessment Overview

Life cycle assessment (LCA) is a standardized procedure used to determine the environmental impacts of products services or goods. The standardized procedure can be described by a four-part framework as outlined by the 14044 ISO standard which includes:

1. Goal and scope definition
2. Life cycle inventory
3. Life cycle impact assessment
4. Interpretation



This integrated framework was inspired by earlier forms of life cycle thinking originating in life cycle financial analysis. Examining a product from origination of materials, to use and disposal provides more holistic analysis of systems that can identify where environmental impacts originate and guide efforts in reducing these impacts.

The ISO standards provides guidance on the structure framework, requirements of data, study assumptions, and methods. With more consistent LCA methodologies, studies are more comparable and of higher scientific rigor. A standardized method helps LCA practitioners manage complex datasets consistently, enable comparisons between different products, and allows benchmarking. Without a standardized method, the results of LCA studies would be even more variable depending on study assumptions and methods. The ISO standards help reduce the influence of practitioner influence on study results.

A brief description of the four steps is provided below before presenting an in-depth description of each process in the following section.

Inventory analysis

The life cycle inventory (LCI) represents the most laborious step of a LCA where data is collected and organized for further analysis. This step often involves contacting companies, literature review, and building models in life cycle assessment software. Material flows in and out of processes, types of materials, product life time, and product energy requirements are examples of data typically collected in the LCI phase.

Life Cycle Impact Assessment

The life cycle impact assessment (LCIA) step of the analysis process takes life cycle inventory data and computes values that represent some form of environmental impacts. This process simplifies the data set from hundreds of flows into 10 or less impact categories that can then be used for decision making. There are many different methods for LCIA based on location, goal and scope of the study.

Interpretation

The interpretation step of LCA reflects on what was found in the other steps to create new knowledge. It should be noted that the interpretation step is not the last step, rather it is continually done throughout each process. When this is done in each stage, study assumptions, goals and scopes, and methods are often refined to better suit the needs of the study commissioner.

Integrated Postharvest Supply Chain Analysis and Life Cycle Assessment Approach

The environmental analysis leverages a framework called Life Cycle Assessment (LCA) that is used to quantify the material inputs and outputs and quantify the environmental impacts of resource use and emissions to the environment. Postharvest solutions analyzed through the lenses of life cycle assessment offers a new approach to identify inefficiencies and determine key leverage points where changes made can create the most positive benefits.

Postharvest losses occur across the value chain for all crops in all economies; however, in Rwanda there are particularly high postharvest losses. These losses directly reduce the final yield of the saleable and consumable product. Reduced product yield translates to more land, water, fertilizers, chemicals, and other inputs per kg or mass of final product sold to a consumer. The LCA framework can quantify the wasted resources and land resulting from postharvest losses. Reducing postharvest losses is key to reducing the environmental impacts of agriculture products and conserving the limited resources in Rwanda.

Environmental sustainability analysis will focus on fossil fuel use and GHG emissions associated with the crop value chain. The environmental hotspots, or stages after harvest that create the most environmental impacts, will be identified. GHG emission and energy use associated with new postharvest practices resulting from this work will be determined and compared to the business as usual values. This will ensure that postharvest improvements will also benefit the environment and will help ensure a sustainable and more prosperous future for the people of Rwanda.

System boundary

The system boundary for an LCA defines what is and what is not included within an analysis. Processes or stages of a product's life cycle within the dashed line are included in the analysis while aspects outside the dashed lines are omitted from the analysis. In the case of Rwandan tomatoes, this study focuses on the growing, processing (sorting and packaging), transportation and wholesale trading of tomatoes.

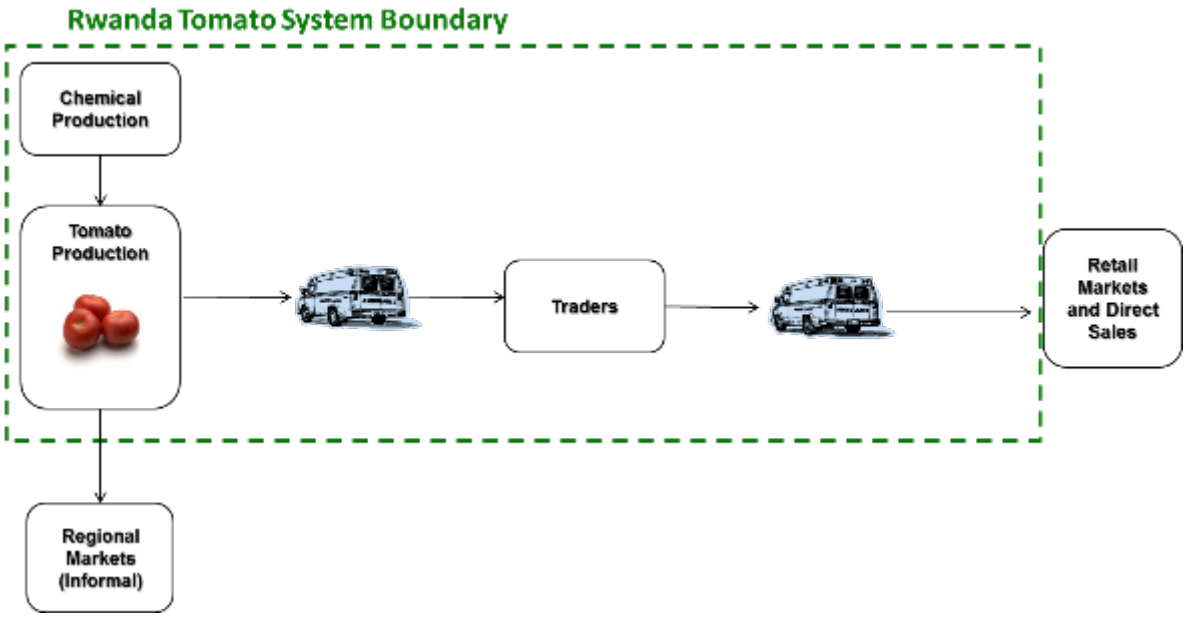


Figure 8: System boundary diagram for tomato production and postharvest supply chain as defined in this study.

Functional unit

The functional unit of a LCA defines the quantity or measure of service for which an analysis is based. In this postharvest analysis, the functional unit is defined as 1 delivered tonne of product. This functional unit includes losses along the postharvest supply chain that occur to deliver one tonne of product.

Data Collection

In this analysis, IPCC 2013 GHG impact assessment method was used.

Primary data

Data was collected from growers within the postharvest supply chain through interviews and surveys. For purposes of the LCA, tomatoes were the case study supply chain where growers were surveyed. This was done to test the validity of primary and secondary data, establish data collection methods, and identify data gaps for further analyses. Data collected for the LCA was supplemented with data from the modified Commodity System Analysis Method (CSAM) assessment. Data from the CSAM assessment included postharvest losses, transportation distances, and other farming practices.

Secondary data

Secondary datasets used were developed from two different sources including literature and existing LCA databases. Country data describing crop yields, planted area, and fertilization rates

were collected from literature sources and Rwandan government documents. In addition to those sources, LCA databases were used including United States Life Cycle Inventory (USLCI) database and the Ecoinvent database. The tomato production process included primary data surrounding farming practices, however, the other agricultural production processes were not surveyed at this time and global average production data were used.

Water Stress Analysis

Irrigation can increase land productivity and provide crop resistance to irregular weather patterns and increase growing seasons. For these reasons, irrigation practices have been on the rise in Rwanda. There are a variety of irrigation systems currently under construction and the potential of these systems is significant in terms of land productivity (MAIMBO et al 2010). The Rwandan Irrigation Master Plan developed by the government of Rwanda and the MINAGRI provides a detailed examination of the potential for increased irrigation in Rwanda as well as some of the challenges that these increases will create.

Within water resource accounting, irrigation water is generally referred to as water consumed as it leaves the watershed in which it originates. Water consumption in areas with plentiful water and low water withdraws can be argued to have lower impacts than water consumption in areas that have few water resources and high demand. The Water Use in LCA (WULCA) working group defined a new metric to quantify the impacts of water consumption referred to as Available Water Remaining (AWARE) method. This method aimed to answer the question "What is the potential to deprive another freshwater user (human or ecosystem) by consuming freshwater in this region?" (Boulay et a. 2017) Using this framework to consider water consumption, it becomes clear that the impacts of water consumption are highly dependent on the region where the water is consumed.

When considering water consumption impacts, a characterization factor is used to multiply the liters or volume of water consumed to get a water equivalents consumed. In areas where water is more scarce and has a higher demand, the characterization factor will be higher. Where water is more available and has lower demands, the characterization factors will be lower. Figure 2 shows the characterization factors for Rwanda that are generally higher on the eastern side (shown in red) of the country and lower on the western side near Lake Kivu (shown in yellow). The characterization factor for the country is 82.4 out of a possible highest value of 100. This indicates that water is more than 80 times more scarce in this region than the world average.

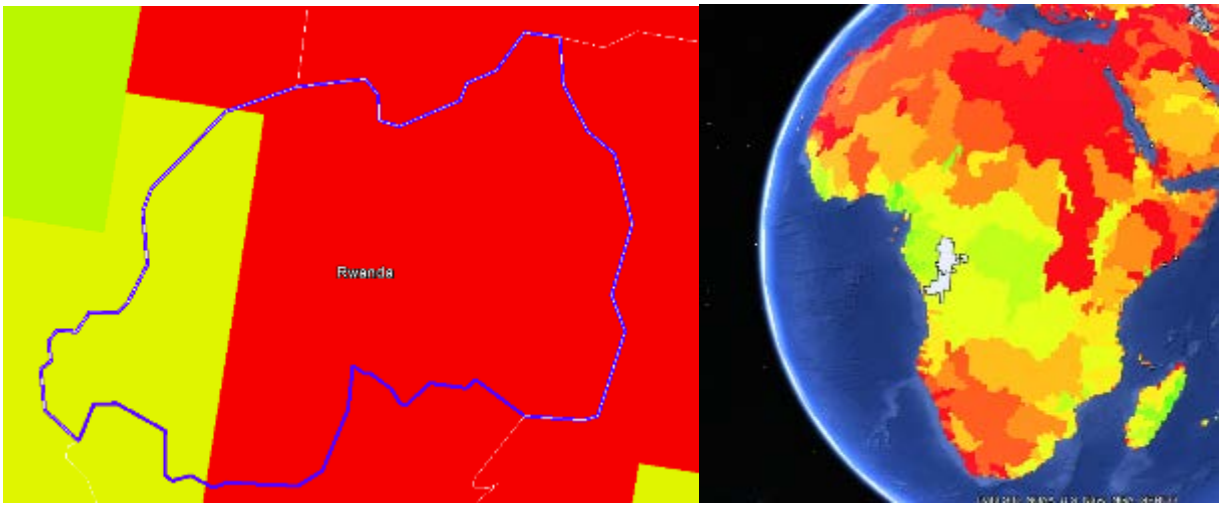


Figure 9: AWARE characterization factors representing water scarcity for Rwanda and Africa

Study Limitations

Primary data collected and presented herein describing agriculture production in Rwanda has limitations due to small samples sizes. To account for small sample sizes, literature and other data sources were also used and compared to the collected data. Much of the life cycle inventory analysis data is based on world average impact data for tomato. There will be significant differences between the world average crop impacts and the impacts resulting from Rwandan agriculture practices, however, the use of world average provides a starting point for further analysis and helps identify hotspots.

Findings

Greenhouse Gas hotspots

Using LCA data representing a world average tomato production there are several main GHG hotspots that carry the majority of the environmental burdens, Figure 3. The fertilizer production and use represent 12% and 23% of total GHG emissions, respectively. When combined, they account for 35% of the total GHG emissions associated with global tomato production. Irrigation is the second largest contributor to GHG emissions. Using petroleum and other fossil fuels to pump water from wells and other surface water supplies requires significant amounts of energy which in turn creates GHG emissions. Pesticide production represents 6% of the total GHG emissions; however, the use of pesticides are generally noted for health and ecosystem impacts and not GHG impacts. Impacts to human health and ecosystems are important; however, beyond the scope of this work. Transportation represents 6% of the total impacts. The GHG emissions before postharvest losses are reported to be 288 kg CO_2 eq. per tonne of tomato.

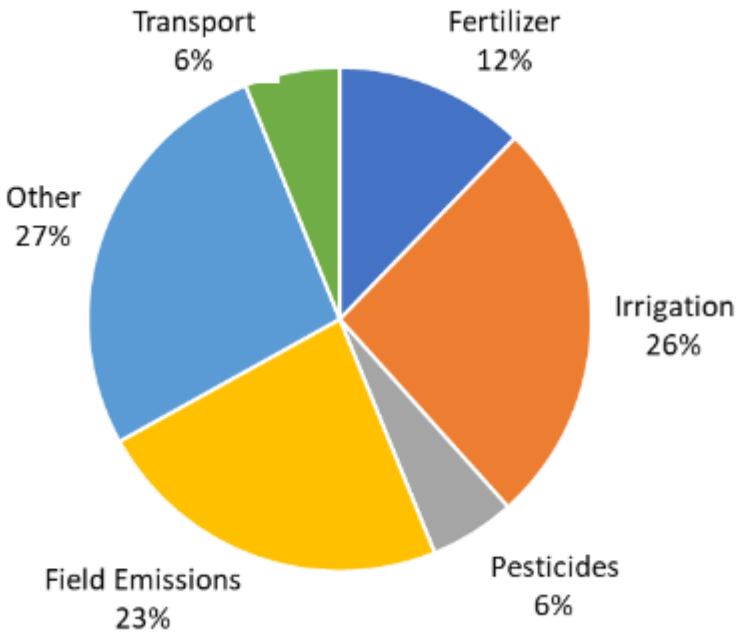


Figure 10: World average tomato production Greenhouse Gas hotspots

Fertilizer Use

Fertilizer use is seen by the Rwandan government as key to increasing land productivity and increased food security. To meet the growing agricultural needs of Rwanda, the government provides fertilizer use guidelines and subsidized or free fertilizers to farmers. These guidelines are meant to be a broad reaching effort with easily understood guidelines to increase fertilizer use, however, guidelines do not account for the fertilizer needs of the soil. Depending on the soil quality and residual nutrients from applied fertilizer from previous crops, there are large variations in the quantity of nutrients needed to optimally grow a specified crop.

There are many issues associated with overuse of chemical fertilizers including land salinization, soil acidification, and nutrient runoff into surface water. These issues as well as others can cause serious harm to the environment as well as decrease the overall land output over time. This analysis will examine the fertilizer recommendations and the environmental impacts associated with fertilizer use. Then the analysis will incorporate surveyed quantities of fertilizer use and compare these to the recommended quantities. These comparisons will then be interpreted and recommendations will be presented.

Recommended fertilizer use

Rwandan ministry of agriculture (MINAGRI) created recommended fertilization quantities to be used for different crops. These recommendations are then communicated to farmers by the local agronomist within the region. Table 2 lists the recommended NPK and UREA fertilizer amounts for tomatoes. The recommendations were reported as kg per hectare as well as kg

per smaller denominations of land area. Based on these fertilization rates and emission and energy use factors from Fertilizer Europe (Bentrup 2014), there is approximately 291 and 470 kg CO2 eq per hectare fertilized with recommended amounts of NPK and Urea, respectively. Fertilizers are also energy intensive to produce requiring 3,045 and 3,518 MJ per hectare for NPK and Urea, respectively.

Table 12: Fertilizer guidelines and associated CO2 eq. emissions

Fertilizer	kg/ha	kg CO2 eq/kg	Kg CO2 eq/ha	MJ /kg	MJ/ha
NPK 17-17-17	355	0.82	291.1	8.58	3045.9
UREA	150	3.13	469.5	23.45	3517.5

The emissions associated with the fertilization can be delineated into two forms: Production emissions and use emissions in the field. Figure 4 demonstrates the oxidation of nitrogen that occurs in the field and emits the powerful greenhouse gas N2O. For most fertilizers containing nitrogen, the field emissions are greater than the emissions from fertilizer production.

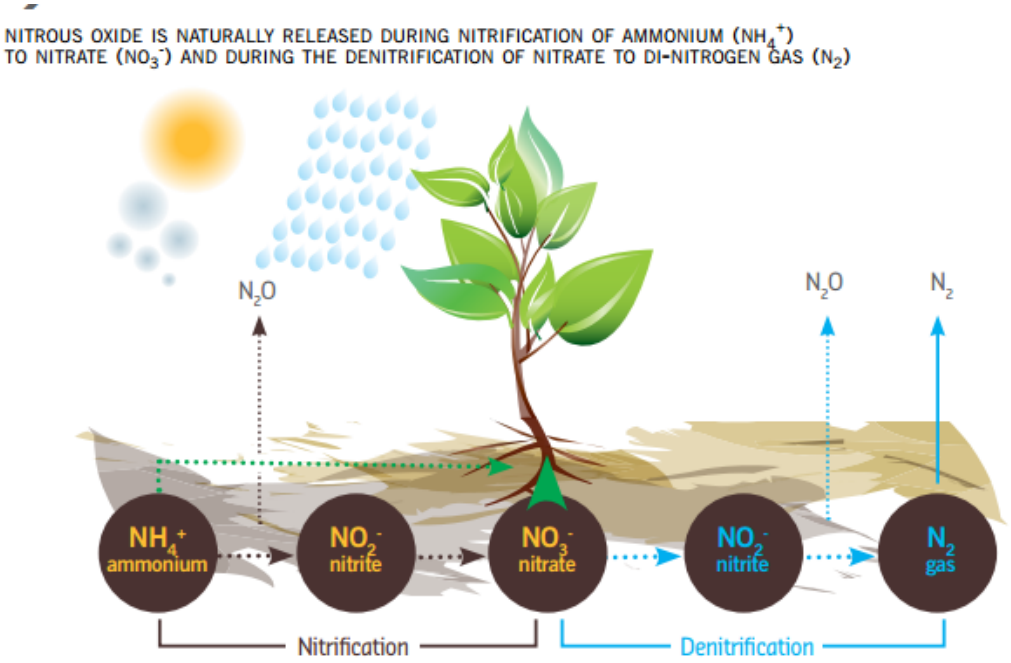


Figure 11: Nitrogen flows due to soil fertilizer use

When the recommended fertilization rates are scaled to the country production in 2014, 5,775 tonnes of CO2 eq. (Table 13) are released to the environment and more than 49,000 Giga-Joules (GJ) of fossil fuel are consumed. However, currently the fertilizer adoption rates are not

up to the recommended levels and thus current emissions and energy use are lower.

Table 13: Greenhouse gas emissions and fossil fuel use associated with tomato fertilizer use based on MINAGRI fertilization guidelines.

Fertilizer	Kg CO2 per kg tomato	MJ Fossil fuel /kg tomato	Total Tonnes CO2	Total GJ Fossil Fuel
NPK 17-17-17	1.45E-02	1.52E-01	2,210	23,128
UREA	2.35E-02	1.76E-01	3,565	26,708
Total	**3.80E-02**	**3.28E-01**	**5,775**	**49,836**

Observed fertilizer use

The recommended fertilization rates are guidelines for farmers, however, the surveyed farmers used lower rates of fertilizers for their tomato crops, Table 4. The surveyed growers indicated they had access to fertilizers, however, many did not use the recommended application rates. Most growers did, however, use organic fertilizers in addition to synthetics as is recommended by MINAGRI.

The farmers were also asked if they used soil testing to determine the optimal fertilizer application rates. None of the farmers indicated they used soil tests due to cost and availability. One grower indicated that he plans to in the future but had not as of the survey date.

Table 14: Observed fertilizer use rates

Fertilizer	kg /Hectare
DAP	52.9
NPK 17-17-17	315
Urea	76.5

Irrigation

Within Rwanda, certain areas grow more tomatoes due largely to demand but also environmental conditions. Figure 12 shows tomato sales by region within Rwanda highlighting the concentration of production around Kigali. As the production of tomatoes follows the demand by population centers, the water availability is often inversely correlated to highly populated areas. In Rwanda, the majority of the tomato and other horticulture production occurs in the areas with the highest water scarcity as defined by Boulay et al. 2017.

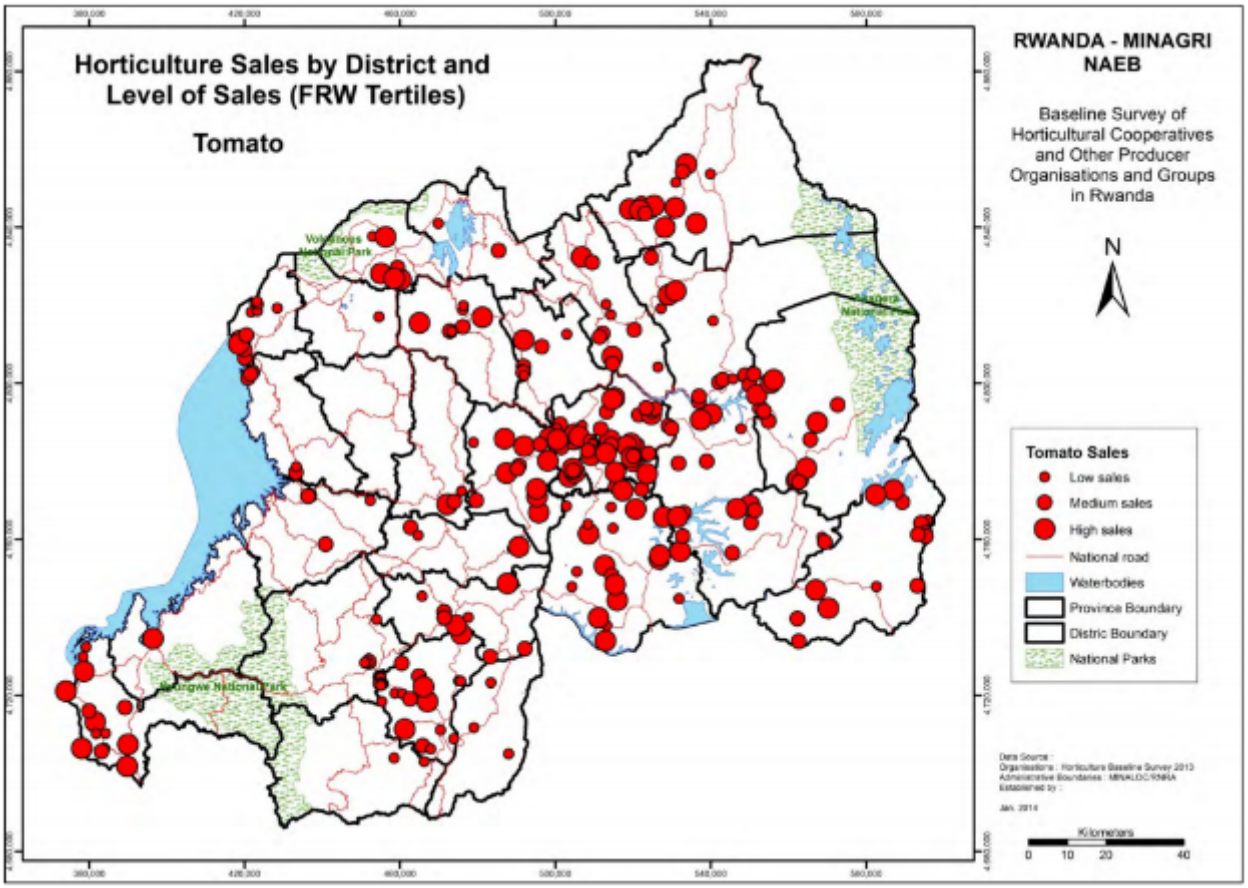


Figure 12: Rwandan tomato sales by district (Clay, D. and Turatsince, J. 2014)

The AWARE characterization factor for water scarcity can be applied to tomato production water consumption primarily resulting from irrigation. Across Rwanda, the irrigation practices are variable due to water availability and infrastructure to irrigate. Some growers with plots of one hectare had access to irrigation water in the forms of manmade irrigation channels or lakes. They often used small gas powered pumps to flood the fields twice a week for as much as eight hours to accomplish their irrigation goals. The direct quantity of water used by growers in Rwanda is difficult to determine with the collected data and the high grower irrigation variability, however, data describing world average water consumption for tomatoes is available and can be used to understand aspects of water consumption for tomatoes in Rwanda.

Using database sources and literature sources, the world average use for tomato ranges from 154 to 186 H2O per kg of tomato (Ecoinvent 2012; Hoekstra et al. 2006). In most cases, water used in irrigation is consumed or does not return to the water source in the watershed it originated from. As such, the water consumption associated with tomato production is assumed to be the same as the tomato water use.

Using the average water consumption per kg tomato produced, the total water consumption for tomato production in Rwanda can be determined, Figure 6. In 2014, approximately 23,000 cubic meters of water was consumed during tomato production. Given the FAO estimate of 4 cubic meters per year per capita water consumed in Rwanda, the water consumed by tomato production in 2014 is equivalent to water use of 93,000 average Rwandan people.

In Rwanda, the water consumed by tomato production in 2014 is equivalent to water use of 93,000 average Rwandan people.

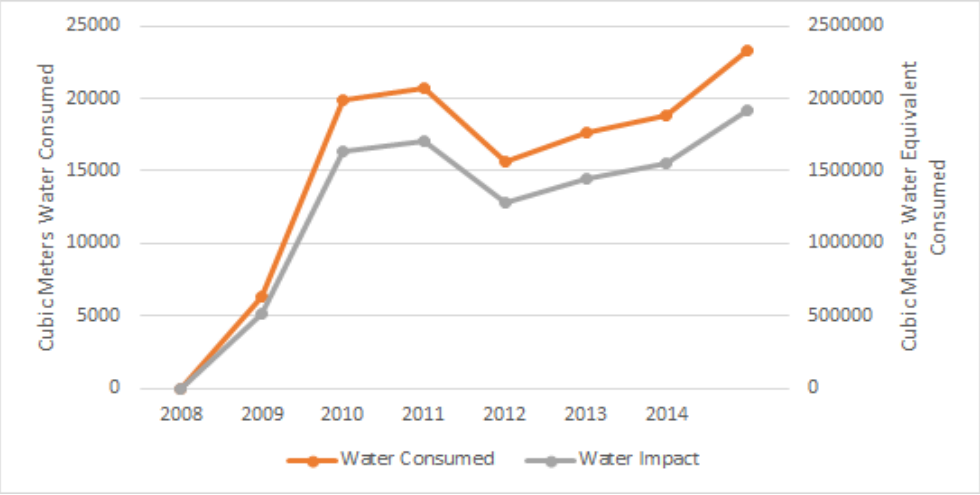


Figure 13: Rwandan tomato production water consumption and impacts (AWARE Method)

Impact of Postharvest Losses

The CSAM analysis determined that the tomato postharvest supply chain had an average loss of 56%. The average of 56% losses was used for the environmental analysis; however, it is

recognized that the loss data is limited and there is likely significant variation between value chains. The losses were highest at the farm level with losses ranging from 5%-40%. The other stages in the value chain reported losses from 4.5% to 20% in the retail market.

Using the reported losses and the emissions and resource use per tonne of tomatoes, the environmental impacts and resource use for the postharvest system were determined, Table 15. Per tonne of tomatoes produced, 21 kg of fertilizers are lost due to postharvest losses. This fertilizer loss has multiple implications to the environment and to the financial performance of the value chain. The wasted fertilizers not only have a financial cost to the grower, but the continued use of fertilizers can lead to soil quality issues such as Ph imbalances and soil salinization. Beyond impacts that directly affect the grower, the GHG emissions associated with the production and use of the fertilizer is significant. The fertilizer emissions associated with the losses from one tonne of tomatoes was determined to be 38 kg CO_2 eq. The total GHG emissions associated with postharvest losses are 161 kg kg CO_2 eq. per tonne of tomatoes.

Table 15: Impacts and resource use from postharvest losses of tomatoes.

Category	Units	Postharvest loss impacts per tonne	Loss impacts total Rwanda Tomato Production
Greenhouse gas emissions	kg CO2 eq.	161	3,000,000
Water volume	m^3 H2O	86	13,000,000
Water equivalents	M^3 H2O eq.	7,073	1,080,000,000

In Rwanda water resources are scarce during the dry season and distributed unevenly throughout the country. Some growers have access to irrigation which provides benefit of increased yields and less chance of failed crops, however, this irrigation puts further strain on already scarce water resources. The tomato losses account for 86 cubic meters of water per tonne of tomatoes. This number represents the amount of water consumed to grow the amount of tomatoes that are lost per tonne of tomatoes delivered to the market. In addition to the quantity of water consumed in tomato production, the water equivalents were determined to relate the consumption to availability of water within Rwanda. Using the AWARE water accounting method, the water equivalents associated with the postharvest losses are 7,073 m^3 per tonne of tomatoes.

Recommendations

The Rwandan postharvest supply chain has a high level of losses that were quantified in the CSAM and the value chain analyses. Some losses come in the form of value loss and other in the form of produce that is not eaten. There are specific postharvest supply chain

recommendations from both reports that outline key changes that will decrease losses. This Lifecycle Assessment report leveraged postharvest loss data from the two reports, as well as identified the major environmental hotspots within the tomato value chain.

Fertilizer application

The grower interviews provided key data used in this analysis as well as insights into ways in which growing practices can be changed to decrease resource use and environmental impacts. As identified earlier in this report, fertilizers are a major contributor to GHG and consume large amounts of energy during production. Additionally, though not quantified herein, they contribute to nutrient loading and can cause water quality issues. Despite this, there are major benefits of fertilizer use that must be balanced against the impacts and where fertilizers are used, they should be used effectively.

The grower survey asked if the farmers performed a soil test to determine the amount of fertilizers needed prior to their application. None of the surveyed farmers used a soil test prior to fertilizer application, however, one grower was planning to in the future. Testing soil prior to fertilizer application is a widespread practice in more advanced agriculture systems that helps the grower deliver the optimal amount of nutrients that maximize yields while reducing the negative aspects of the fertilizer use. With the Rwandan goal to drastically increase fertilizer use, the adoption of soil testing will reduce the wasted fertilizers, increase yields, and avoid unwanted impacts to the environment. It is recognized that fertilizers are still underutilized within Rwanda, however, current fertilizer operations can be improved by soil tests and prevent the negative impacts to soil quality that can occur. To do this, soil tests could be distributed to the farmers or performed by the local agronomist before crop nutrients are recommended and applied.

Water resources

The irregularity of water availability makes Rwandan agriculture high risk for non-irrigated growers which makes up the majority of land holders. Government and international donor funded projects have installed irrigation infrastructure in many Rwandan regions as well as drained swamps for agriculture, however, these projects serve a small fraction of farmers and are usually targeted at higher value crops. To serve smallholder farmers, rainwater capture has been proposed to be a viable and low cost option (Jama and Pizarro, 2008). The capture of rainwater that would otherwise go unused for agriculture provides additional resources to growers during the dry season (June to mid-September) while not infringing on the other water needs during the dry season. With increased levels of irrigation availability, the farmer takes on less risk and has a lower chance of a failed crop. With lower crop failure risk, the farmers can more reasonably take on additional financial investment in fertilizers that will increase yields.

At a higher level, increased irrigation can lead to higher levels of food security within the country, however, the irrigation needs must be balanced with other water resource needs of humans and the environment in order to avoid unintended consequences of increased irrigation.

Future Work

The environmental data used in this work is derived from both literature and grower interviews. In future efforts, more grower interviews would help provide a more representative dataset describing agriculture systems. In addition to a larger set of grower interviews, the grower practices should be delineated into different types of systems such as irrigated, swamp grown, and non-irrigated. Data characterizing these different growing regions would be helpful to gain a more comprehensive understanding of all the major growing practices and their environmental impacts.

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Annexes

Annex 1: CSAM Questionnaires and worksheets

ANNEX 1A: CSAM SUMMARY QUESTIONS LIST

Crop value chain assessment for the Reducing Postharvest Losses in Rwanda project.

CROP # 1 _____

Components 1 - 7: Pre-Production

(Date sources include extension workers, researchers, project partners)

1- Importance of the crop. What is the relative importance of the crop? Base your estimate of importance on information on number of Farmers, amount produced, area of production, and/or market value.

2- Governmental policies. Are there any laws, regulations, incentives or disincentives related to producing or marketing the crop? (e.g., existing price supports or controls, banned pesticides or residue limits)

3- Relevant institutions. Are there any organizations involved in projects related to production or marketing the crop? What are the goals of the projects? How many people are participating?

4- Facilitating services. What services are available to Farmers and marketers (for example: credit, inputs, technical advice, subsidies)?

5- Farmer/shipper organizations. Are there any Farmer or marketer organizations involved with the crop? What benefits or services do they provide to participants? At what cost?

6- Environmental conditions. Does the local climate, soils or other factors limit the quality of production? Are the cultivars produced appropriate for the location?

7- Availability of planting materials. Are seeds or planting materials of adequate quality? Can growers obtain adequate supplies when needed?

Components 8 - 11: Production (Data sources include farmers, extension workers, project staff)

8- Farmers' general cultural practices. Do any farming practices in use have an effect on produce quality (irrigation, weed control, fertilization practices, field sanitation)?

9- Pests and diseases. Are there any insects, fungi, bacteria, weeds or other pests present that affect the quality of produce?

10- Pre-harvest treatments. What kinds of pre-harvest treatments might affect postharvest quality (such as use of pesticides, pruning practices, trellising, thinning)?

11- Production costs. What are the costs of any proposed alternative methods?

Components 12 - 21: Postharvest
(Data sources include farmers, extension workers, marketers, processors, project partners)
12- Harvest. When and how is produce harvested? by whom? at what time of day? Why? What sort of containers are used? (if possible, take photos). Is the produce harvested at the proper maturity for the intended market? What is the temperature at harvest time? What amounts and types of losses are observed/reported?
13- Grading, sorting and inspection. How is produce sorted? by whom? Does value (price) change as quality/size grades change? Do local, regional or national standards (voluntary or mandatory) exist for inspection? What amounts and types of losses are observed/reported? What happens to culled produce?
14- Postharvest treatments. What kinds of postharvest treatments are used? (Describe any curing practices, cleaning, trimming, hot water dips, etc.) Are treatments appropriate for the product? (if possible, take photos).
15- Packaging. How is produced packed for transport and storage? What kind of packages are used? Are packages appropriate for the product? Can they be reused or recycled? (if possible, take photos).
16- Cooling (if any). When and how is produce cooled? To what temperature? Using which method(s)? If temperature measured during cooling? Are methods appropriate for the product? If produce is not cooled. What is the ambient temperature range during the postharvest period?
17- Storage (if any). Where and for how long is produce stored? In what type of storage facility? Under what conditions (packaging, temperature, RH, physical setting, hygiene, inspections, etc.)? Is the temperature measured while the produce is in storage? (if possible, take photos).
18- Transport. How and for what distance is produce transported? In what type of vehicle? How many times is produce transported? How is produce loaded and unloaded? (if possible, take photos).
19- Delays/ waiting. Are there any delays during handling? How long and under what conditions (temperature, RH, physical setting) does produce wait between steps?
20- Other handling. What other types of handling does the produce undergo? Is there sufficient labor available? Is the labor force well trained for proper handling from harvest through transport? Would alternative handling methods reduce losses? Would these methods require new workers or displace current workers?
21- Agro-processing (if any). How is produce processed (methods, processing steps) and to what kinds of products? How much value is added? Are sufficient facilities, equipment, fuel, packaging materials and labor available for processing? Is there consumer demand for processed products?

Components 22 - 26: Marketing

(Data sources include farmers, traders, wholesale marketers, retail marketers, consumers, extension workers, project partners)

22- Market intermediaries. Who are the handlers of the crop between Farmers and consumers? How long do they have control of produce and how do they handle it? What amounts and types of losses are observed/reported? Who is responsible for losses /who suffers financially? Is produce handled on consignment; marketed via direct sales; move through wholesalers?

23- Market information. Do handlers and marketers have access to current prices and volumes in order to plan their marketing strategies? Who does the recordkeeping? Is information accurate, reliable, timely, and useful to decision makers?

24- Consumer demand. Do consumers have specific preferences for produce sizes, flavors, colors, maturities, quality grades, packages types, package sizes or other characteristics? Are there any signs of unmet demand and/or over-supply? How do consumers react to the use of postharvest treatments (pesticides, irradiation, coatings, etc.) or certain packaging methods (plastic, Styrofoam, recyclables)?

25- Exports. Is this commodity produced for export? What are the specific requirements for export (regulations of importing country with respect to grades, packaging, pest control, etc.)?

26- Marketing costs. Do handlers/ marketers have access to credit? Are prevailing market interest rates at a level that allows the borrower to repay the loan and still make a profit? Is supporting infrastructure adequate (roads, marketing facilities, management skills of staff, communication systems such as telephone, FAX, e-mail services)? What are the costs of any proposed change in marketing practices?

ANNEX 1B: ON FARM DATA COLLECTION WORKSHEET

ON FARM DATA COLLECTION WORKSHEET				Name of Data Collector:			
TOMATOES	Variety (if known _____) or describe color, shape, etc						
Code: Farm____							
Questions and observations	At Harvest			Farm gate			
Date							
Location of farm							
Size of farm							
Crops produced							
Season for tomatoes (range of harvesting dates on this farm)							
Name of destination market if known							
Distance to market if known	_____km			Expected journey time _____hou			
Sorting - selecting out that produce which will not be sent to the market	Was sorting done at harvest? Yes/ No	If Yes, estimate waste (discarded) _____% or left on the vine _____% Reason for sorting out:		Was sorting done before farm gate sale? Yes/No	If Yes, estimate (discarded):___ Reason for sorti		
Size Grading : is there any grading into different sizes on the farm?	If Yes, estimate % in each category: Large ____% ; Medium ____% ; Small ____%			If Yes, estimate % in each catego Large _____% ; Medium ____% ; S ____%			
Does price offered vary by quality grade?	Describe grading criteria:			If Yes, what is the price offered quality grade? Highest __ Middle _____ ; Lowest _____			
Expected farm gate price:				Price offered _____ (by weigh Volume? By Number of containe Price per kg: _____			
MEASUREMENTS	**At Harvest**			**Farm gate (to be measured aga possible)**			
Sample size (select random samples)	count of 20			count of 20			
Time from harvest	0 hour						
Time of day							
Air temperature	_____ C			_____ C			
Relative humidity indicator	Wet bulb T: _____ Dry bulb T : _____			Wet bulb T: _____ Dry bulb T : _			
Pulp temperature in °C (3 randomly selected fruits)							
Quality sort for defects, decay, damage (# out of count of 20) Ratings from 5= Extreme defects, decay or damage; 3 = moderate; 1 = none	Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 _____			Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 _____			
number with obvious defects ie: cracks, sunburn, misshapen, etc							

TOMATOES Worksheet
Code: Farm____

ANNEX 1C: PACKINGHOUSE DATA COLLECTION WORKSHEET

PACKINGHOUSE DATA COLLECTION WORKSHEET			Name of Data Collector:	
TOMATOES	Variety (if known _____) or describe color, shape, etc			
Code: PACKING____				
Questions and observations	On Arrival		At time of sale	
Date				
Name of packinghouse or collection center				
Location of market				
Season for tomatoes (range of dates of sales at this market)				
Distance from farm if known	_____km			
Sorting - selecting out that produce which will not be resold	Was sorting done before delivery? Yes/ No	If Yes, estimate waste (discarded) _____% Reason for sorting out:	Was sorting done before sale? Yes/No	If Yes, estimate (discarded):___ Reason for sorti
Size Grading : is there any grading into different sizes at the market?	If Yes, estimate % in each category: Large ____% ; Medium ____% ; Small ____%		If Yes, estimate % in each catego Large ____% ; Medium ____% ; S ____%	
Does price offered vary by quality grade?	Describe grading criteria:		If Yes, what is the price offered quality grade? Highest __ Middle _____ ; Lowest _____	
Expected wholesale price:			Price range _____ (by weight? Volume? By Number of container Price per kg: _____	
MEASUREMENTS	**on Arrival**		**At time of sale (to be measured if possible)**	
Sample size (select random samples)	count of 20		one package (_____ = total nu	
Time from harvest (if known)				
Time of day				
Air temperature	_____ C		_____ C	
Relative humidity indicator	Wet bulb T: _____ Dry bulb T : _____		Wet bulb T: _____ Dry bulb T : _	
Pulp temperature in °C (3 randomly selected fruits)				
Quality sort for defects, decay, damage (# out of count of 20) Ratings from 5= Extreme defects, decay or damage; 3 = moderate; 1 = none	Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 _____		Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 _____	
number with obvious defects ie: cracks, sunburn, misshapen, etc				

TOMATOES Worksheet
Code: PACKING____

ANNEX 1D: WHOLESALE DATA COLLECTION WORKSHEET

WHOLESALE DATA COLLECTION WORKSHEET			Name of Data Collector: Wilberforce
TOMATOES	Variety (if known _____Not known_____) or describe color, shape, etc		
Code: WhSale 06			
Questions and observations	On Arrival		At time of sale
Date	2/11/16		4th/11/2016
Name of market	wsale pick up(bicycle)		
Location of market			Zinia Kigali
Season for tomatoes (range of dates of sales at this market)			
Distance from farm if known	_____km		43 km
Sorting - selecting out that produce which will not be resold	Was sorting done before delivery?Yes / No	If Yes, estimate waste (discarded) _____% Reason for sorting out:	Was sorting done before sale? Yes/No / If Yes, estimate (discarded):___ Reason for sorti
Size Grading : is there any grading into different sizes at the market?	If Yes, estimate % in each category: Large ___% ; Medium ____% ; Small ____%		If Yes, estimate % in each catego Large _____% ; Medium ____% ; ____%
Does price offered vary by quality grade?	Describe grading criteria:		If Yes, what is the price offered quality grade? Highest __ Middle _____ ; Lowest _____
Expected wholesale price:			\
MEASUREMENTS	on Arrival		At time of sale (to be measurec if possible)
Sample size (select random samples)	count of 20		one package (_____ = total nu
Time from harvest (if known)			
Time of day			
Air temperature	____ °C		_____ C
Relative humidity indicator	Wet bulb T: ___c__ Dry bulb T : °C__		Wet bulb T: _____ Dry bulb T : _
Pulp temperature in °C (3 randomly selected fruits)			
Quality sort for defects, decay, damage (# out of count of 20) Ratings from 5= Extreme defects, decay or damage; 3 = moderate; 1 = none	Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 ____		Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 _____
number with obvious defects ie: cracks, sunburn, misshapen, etc			

TOMATOES Worksheet
Code: WhSale____

ANNEX 1E: RETAIL DATA COLLECTION WORKSHEET

RETAIL DATA COLLECTION WORKSHEET				Name of Data Collector:			
TOMATOES	Variety (if known _____) or describe color, shape, etc						
Code: Retail____							
Questions and observations	On Arrival			6 to 8 hours after arrival			
Date							
Name of market							
Location of market							
Season for tomatoes (range of dates of sales at this market)							
Distance from wholesale market	_____km						
Sorting - selecting out that produce which will not be resold	Was sorting done before purchase? Yes/ No	If Yes, estimate waste (discarded) _____% Reason for sorting out:		Was sorting done before sale? Yes/No	If Yes, estimate (discarded):___ Reason for sorti		
Size Grading : is there any grading into different sizes at the market?	If Yes, estimate % in each category: Large ____% ; Medium ____% ; Small ____%			If Yes, estimate % in each catego Large ____% ; Medium ____% ; S ____%			
Does price offered vary by quality grade?	Describe grading criteria:			If Yes, what is the price offered quality grade? Highest __ Middle _____ ; Lowest _____			
Expected retail price:				Price range _____ (by wei Volume? By number?) P kg: _____			
MEASUREMENTS	on Arrival			6 to 8 hours after arrival			
Sample size (select random samples)	count of 20			count of 20			
Time from harvest (if known)							
Time of day							
Air temperature	_____ C			_____ C			
Relative humidity indicator	Wet bulb T: _____ Dry bulb T : _____			Wet bulb T: _____ Dry bulb T : _			
Pulp temperature in °C (3 randomly selected fruits)							
Quality sort for defects, decay, damage (# out of count of 20) Ratings from 5= Extreme defects, decay or damage; 3 = moderate; 1 = none	Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 _____			Number of rating 5 _____ Number of rating 3 _____ Number of rating 1 _____			
number with obvious defects ie: cracks, sunburn, misshapen, etc							

TOMATOES Worksheet
Code: Retail____

Annex 1 F: Cost/Benefit worksheet

Costs and Benefits Worksheet

For any observed IMPROVED postharvest handling technology or practice:
Assume harvest 1000 kg

Crop_____ Country: Rwanda Region_____

	Current Practice	New Practice
Describe:		
COSTS		
Relative cost		
EXPECTED BENEFITS		
% losses		
Amount for sale		
Value/kg		
Total market value		
Market value minus costs		
Relative profit		
ROI		

Annex 1G: Data Collection Protocol

HOW TO USE THE POSTHARVEST DATA COLLECTION WORKSHEETS

SITE SELECTION:
The project will cover the traditional domestic marketing value chains. Tomato and the sites where it is grown are chosen because goes into the typical domestic wholesale market chain and not to export or supermarkets.
The individual sheets are code numbered (Tomatoes Farm01, Tomatoes Whsale02, etc up to 10 complete sets of data at the farm, wholesale market and retail market.
It is useful to ask questions to the farmer will know what happens between harvest and the farm gate, the wholesaler will be able to tell what happens between purchase and resale, etc.

Measurements
Averages will be calculated via computer once all the raw data (the actual readings or measurements) is submitted.

FARM
The data is collected during harvest at the farm gate.
The change in weight is the information of highest interest, one random sample of 20 fruits is put aside and the weigh is taken at harvest and again at farm gate.

COLLECTION CENTER or PACKHOUSE
Data is collected upon arrival and upon sale (loading or departure)

WHOLESALE MARKET
Purchase the produce from the wholesale market at the time of arrival, do our measurements and then hold our sample until the lot is sold (and take the readings again) keeping the sample in similar conditions to the lot that is being sold (ex: exposed to the sun).

RETAIL MARKET
Collect data only at open street style markets. If we try to add shops, supermarkets, export markets, etc, we will have too little data from these diverse markets to make any conclusions. Retails samples of 20 randomly selected items of produce will need to be purchased from the vendor.

PACKAGE:
<u>Protection</u>

The package protection strength is evaluated as

- 5=very strong, protective
- 4= strong, moderately protective
- 3=somewhat strong, somewhat protective
- 2=weak, not very protective
- 1=no package or very weak, offering no protection

Description of package or container

- Type
- material
- dimensions
- cooling efficiency

TAKE PHOTOS: Photos are good indicators of visual defects, maturity or quality rating scales. Photos of defects or damages, should be labeled using the same code as the worksheet plus a descriptive name (ex: Tomatoes Farm 01 damage1, Tomatoes Whsale 02 decay1, etc)

ANNEX 2: LIST OF TOOLS FOR THE FIELD

- The Oseri Pronto digital scale operates on 2 AAA batteries, has a capacity of 1.0 gram to 5,050 grams, with a tare feature. It weighs 300 grams and measures 8.2 x 1.8 x 6 inches and comes with a one-year warranty. It has received a 4.5 star Amazon rating (5.0 max) from 9,669 purchasers.
- The Camry Luggage Scale has a capacity of 50 kg, and is suitable for weighing crates of produce. It has a tare function and operates on one 3v lithium battery cell CR2032. It weighs 7180 grams. It has received a 4.5 star Amazon rating (5.0 max) from 283 purchasers.
- The Taylor Precision Waterproof Digital Thermometer Probe:with a range of -40 to 230 Celsius. It has a hold feature, allowing remote readings, and is fully waterproof. It is a pen-style instrument with a lanyard for easy field use. It has received a 4.0 star Amazon rating (5.0 max) from 9,669 purchasers.
- Tools for measuring wet bulb T using the digital thermometer probe: (for RH calculations): 10 cm of cotton gauze, tie to bind gauze to T. probe, water to saturate gauze, psychometric chart and instructions for how to use
- TOMATO RIPENESS CHART (UC DAVIS)

Annex 3: LIST OF INTERVIEWEES

List of CSAM Interviewees for Open Field Tomatoes CSAM: Rwanda October and November 2016

No	DATE	LOCATION	NAME	AFFILIATION	PURPOSE
1	27-Oct-16	Kimisagara Market - Kigali	Nyiranshuti Helena	Tomato retailer	Retail data collection
2	28-Oct-16	Biryogo market-Bugesera	Nyirahabimana Marie Claire	Tomato retailer	Retail data collection
3	28-Oct-16	Biryogo market-Bugesera	Utuwe Marie Lucie	Tomato retailer	Retail data collection
4	28-Oct-16	Biryogo market-Bugesera	Mukashyaka Liberata	Tomato retailer	Retail data collection
5	28-Oct-16	Bugesera- Gashora	Habumuremyi Martin	Tomato farmer	Farm data collection
6	28-Oct-16	Bugesera- Gashora	Rutabayiru Kabare Damien	Agronomist	CSA questionnaire interview
7	31-Oct-16	Rwempasha-Nyagatare	Rutaneshwa Valens	Tomato farmer	Farm data collection
8	31-Oct-16	Rwempasha-Nyagatare	Mazuru Diogene	Tomato wholesaler	Wholesale data collection
9	31-Oct-16	Rwempasha-Nyagatare	Uwizeyimana Bonaventure	Tomato farmer	Farm data collection
10	31-Oct-16	Nyabugogo market-Kigali	Nyirahabimana Monique	Tomato retailer	Retail data collection
11	31-Oct-16	Nyabugogo market-Kigali	Mukantirenganya Zebria	Tomato retailer	Retail data collection
12	31-Oct-16	Nyabugogo market-Kigali	Mukangwije Dancille	Tomato retailer	Retail data collection
13	31-Oct-16	Rukomo-Nyagatare	Hategekimana Antoine	Tomato farmer	Farm data collection
14	31-Oct-16	Rwempasha-Nyagatare	Misigaro Paul	Tomato farmer	Farm data collection
15	1-Nov-16	Nyabugogo market-Kigali	Uwamahoro Adeliphine	Tomato retailer	Retail data collection

16	1-Nov-16	Nyabugogo market-Kigali	Kubwimana Mediatrice	Tomato retailer	Retail data collection
17	1-Nov-16	Nyabugogo market-Kigali	Nyiramatama Christine	Tomato retailer	Retail data collection
18	1-Nov-16	Nyagatare market-Nyagatare	Hitayezu Jean Pierre	Tomato wholesaler	Wholesale data collection
19	1-Nov-16	Nyagatare market-Nyagatare	Kayumba Leonard	Tomato retailer	Retail data collection
20	1-Nov-16	Nyagatare market-Nyagatare	Muteteri Vestine	Tomato retailer	Retail data collection
21	2-Nov-16	Gashora-Bugesera	Gatabazi Adrien	Tomato farmer	Farm data collection
22	2-Nov-16	Gashora-Bugesera	Niyibizi Aphrodis	Tomato wholesaler	Wholesale data collection
23	2-Nov-16	Gashora-Bugesera	Sibomana Aberi	Tomato farmer	Farm data collection
24	9-Nov-16	Ririma-Bugesera	Kabagamba Alexis	Tomato farmer	Farm data collection
25	11-Nov-16	Nyabugogo market-Kigali	Mutuyinka Valentine	Tomato retailer	Retail data collection
26	11-Nov-16	Nyabugogo market-Kigali	Wihogora Devota	Tomato retailer	Retail data collection
27	11-Nov-16	Nyabugogo market-Kigali	Twishimire Alice	Tomato retailer	Retail data collection
28	11-Nov-16	Nyabugogo market-Kigali	Bankundiye Adela	Tomato retailer	Retail data collection
29	18-Nov-16	Kiyovu-Kigali	Mujawamaria Marie Goretti	Registrar of agrochemicals	CSA questionnaire interview
30	18-Nov-16	Kiyovu-Kigali	Mutoni Teddy	Agriculture product certification	CSA questionnaire interview
31	18-Nov-16	Nyabugogo-kigali	Muteteri Vestine	Agrochemical seller	CSA questionnaire interview
32	18-Nov-16	Nyabugogo -Kigali	Ndayisaba Evariste	Agrochemical seller	CSA questionnaire interview

ANNEX 4: SITES INCLUDED IN THE CSAM CROP STUDY

DISTRICTS:
Kigali
Nyagatare
Muhanga
Nyabugogo
Nyarugenge
Bugesera

Name and location of wholesale markets
Wholesale pickup point (Nyagatare) – collection point near farms
Wholesale pickup point (Nyagatare)
Wholesale pick up point Nyabugogo
Wholesale pick up point Nyagatare, Rwempasa Gasiga cell
Wholesale pick up point Bugesera
Wholesale pick up point
Mutangana market
Nyagatare District, Rwempasha Sector, Gasinga Cell, Gasinga Village
Name and location of retail markets
Kimisagara Market, Nyarugenge District
Biryogo market, Bugesera District, Gashora sector, Biryogo Cell, Biryogo Village
Biryogo market, Bugesera District, Gashora sector, Biryogo Cell, Biryogo Village
Nyabugogo Modern Market, Muhima district
Nyabugogo Modern Market, Nyarugenge District,Muhima sector, Gitega cell
City Valley Market, Nyarugenge District, Nyabugogo Sector, Nyabugogo cell, Ubucuruzi Cell
Nyagatare Market, Nyagatare District
Fresh Food Market or City Valley Market, Nyarugenge District, Muhima Sector , Nyabugogo cell, Ubucuruzi village

Fresh Food Market (City Valley Market), Nyarugenge District , Muhima Sector,Nyabugogo Cell, Ubucuruzi Village
Fresh Food Market (City Valley Market), Nyarugenge District , Muhima Sector,Nyabugogo Cell, Ubucuruzi Village
Fresh food market (City Valley market), Nyabugogo
Fresh Food Market (City valley market), Nyabugogo
Fresh Food Market (City valley market), Nyabugogo
Fresh Food Market (City valley market), Nyabugogo

DATA COLLECTION GPS WORKSHEET AT RETAIL LEVEL

Retail	Data collector	Location	Collection Dates and Time	Electronic copy	Photo	GPS Coordinates	Contact List
01	Solange	Kimisagara	27/10/2016,12:17 PM			-1.959555 30.054132	
02	Solange	Kimisagara				-1.959555 30.054132	
03	Bernard, Godelieve	Gashora	28/10/2016,2:15 PM			-2.208054 30.246874	
04	Bernard, Solange	Gashora	28/11/2016,10:30 AM			-2.208054 30.246874	
05	Godelieve	Boryogo-Gashora	28/10/2016,3:55 PM			-2.208054 30.246874	
06	Solange	Nyabugogo	31/10/2016,08:40 AM			-1.940958 30.046829	
07	Solange	Nyabugogo	31/10/2016,11:52 PM			-1.940958 30.046829	
08	Solange	Nyabugogo	31/10/2016,15 PM			-1.938955 30.048491	

09	Godelieve	Nyagatare	1/11/2016,4:15 PM			-1.287307 30.333298	
10	Godelieve	Nyagatare	1/11/2016,5:30 PM			-1.287307 30.333298	
11	Solange	Nyabugogo	1/11/2016,12:04 PM			-1.938955 30.048491	
12	Solange	Nyabugogo	1/11/2016,13:32 PM			-1.938955 30.048491	
13	Solange	Nyabugogo	1/11/2016,3:06 PM			-1.938955 30.048491	

Annex 5: LCA – Mineral Fertiliser Carbon Footprint Reference Values

MINERAL FERTILISER CARBON FOOTPRINT REFERENCE VALUES: 2011, Fertilizers Europe, validated by European Commission methodology.

Fertiliser product	Nutrient content		GHG emissions (GWP 100 yrs: IPCC, 2007)								Energy consumption*
			Fertiliser production	Fertiliser use (soil effects)					Fertiliser production + use		Fertiliser production
			At plant gate	CO_2 from urea hydrolysis	Direct N_2O from use	Indirect N_2O via NH_3	Indirect N_2O via NO_3	CO_2 from liming and CAN	Total	Total	On-site
			kg CO_2 -eq/kg product						kg CO_2-eq/kg product	kg CO_2-eq/kg nutrient	MJ/kg product
Ammonium nitrate	AN	33.5%N	1.18	0.00	1.26	0.01	0.35	0.27	3.06	9.14	14.02
Calcium ammonium nitrate	CAN	27%N	1.00	0.00	0.89	0.01	0.28	0.20	2.40	8.88	11.78
Ammonium sulphate	ANS	26%N, 14%S	0.83	0.00	0.10	0.02	0.27	0.40	2.62	10.09	10.61
Calcium nitrate	CN	15.5%N	0.68	0.00	0.65	0.00	0.16	0.00	1.50	9.67	7.23
Ammonium sulphate	AS	21%N, 24%S	0.58	0.00	0.98	0.02	0.22	0.50	2.30	10.95	8.07
Ammonium phosphates	DAP	18%N, 46%P_2O_5	0.73	0.00	0.76	0.01	0.19	0.34	2.03	11.27	6.76
Urea	Urea	46%N	0.91	0.73	2.37	0.28	0.48	0.36	5.15	11.19	23.45
Urea ammonium nitrate	UAN	30%N	0.82	0.25	1.40	0.10	0.32	0.24	3.13	10.43	13.84
NPK 15-15-15	NPK	15%N, 15% P_2O_5 15% K_2O	0.76	0.00	0.56	0.01	0.16	0.12	1.61	10.71	7.59
Triple superphosphate	TSP	48% P_2O_5	0.26	0.00	0.00	0.00	0.00	0.01	0.27	0.56	0.18
Muriate of potash	MOP	60% K_2O	0.25	0.00	0.00	0.00	0.00	0.00	0.25	0.43	3.00

Annex 6: LCA On Farm Data Collection Worksheet

ON FARM DATA COLLECTION WORKSHEET Name of Data Collector: _____

Code: Farm____

Crop Type			
Survey date		Harvest date	
Years growing this crop		Number of harvest per year	
Grower Demographics	Age	Gender	Education level
How many years:	Growing this crop	Farming	
Farm Data			
Location of farm (GPS)			
Size of farm (hectares)			
Yield (kg product/hectare)	Total product mass (kg)	Production area (m^2 or Hectare)	
Steepness of slope	Low (mostly flat)	Moderate	High (steep)
Soil Characteristics	Clay	Sandy	Loam
Tillage method	A. Mechanical (fuel based)	B. Human powered	C. Animal Powered
Tillage practices	A. Strip till (less than 50cm)	Strip Till (more than 50cm)	C. Full till
Fuel Type for tillage	A. Diesel	B. Petrol	C. Other
Tillage Area	Hectares	Number of times per year	

Crop Nutrients	**Type**	**How many times per harvest**	**Quantity (kg/hectare)**
Fertilizer 1			
Fertilizer 2			
Fertilizer 3			
Other nutrients (list-such as lime or CAN)			
Soil testing performed	A. yes	B. No	C. No and I don't know what that is
If no, why?	I did not have enough money to test	Not available	other: describe

Pesticides, Fungicide and herbicide	Name	Target pest or disease/How many	Quantity (kg/hectare or liters/hectare)
chemical 1			
Chemical 2			

TOMATOES Worksheet
Code: Farm____

Chemical 3			

Irrigation		
Field	Irrigated area	Shared irrigation Yes/no
Schedule	Irrigations per week	Hours irrigated
Pump Fuel Type	A. Diesel B. Petrol C. Electricity	
Irrigation pump	Fuel use per irrigation	pump flow rate (m^3 per time)

Environmental Concerns					
	Rank your concerns				
0 I have not heard of this	1 not concerned	2 neutral	3 slightly concerned	4 concerned	5 very concerned
Soil removed from farm					
Climate change					
Soil quality					
Nutrient runoff					
Water availability					
Water quality					
Smoky air (particulate)					
Land salination					
PH					
Other					

Have you noticed differences in rainy seasons over the past years?	Yes	No	N/A
Have you notice your crop yield over the past three	Increase	Decreas	no
Have you had sufficient access to pesticides and fertilizers?	Yes	No	N/A

List other notes and descriptions here

TOMATOES Worksheet
Code: Farm____