DEVELOPMENT OF A SMART PROTOTYPE SOLAR COOLER TO REPLACE CHARCOAL COOLERS IN MAINTAINING QUALITY AND SHELF STABILITY OF FRENCH BEANS ALONG THE SUPPLY CHAIN IN KENYA

OGUMO ERICK OTIENO

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Ogumo Erick Otieno

This thesis has been submitted for examination with our approval as the University Supervisors

1. Signature____________________ Date________

   Dr. Catherine N. Kunyanga (Ph.D.)

   Department of Food Science, Nutrition and Technology,

   University of Nairobi

2. Signature____________________ Date______________

   Prof. John W. Kimenju (Ph.D.)

   Department of Plant Science and Crop protection,

   University of Nairobi

3. Signature____________________ Date________________

   Prof. Michael W. Okoth (Ph.D.)

   Department of Food Science, Nutrition and Technology,

   University of Nairobi

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DEDICATION

I dedicate this study to my sons Robert Bromley Otieno, Roy Otieno and Ryan Otieno.

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ACRONYMS

BRC	-	British Retail Consortium
CFU	-	Colony Forming Units
DBPS	-	Disinfectant by-products
EPS	-	Expanded Polystyrene
EU	-	European Union
GCCA	-	Global Cold Chain Alliance
G.A.P	-	Good Agricultural Practice
Global G.A.P	-	Global Good Agricultural Practices
GMPs	-	Good Manufacturing Practices
HACCP	-	Hazard Analysis Critical Control Points
HCDA	-	Horticultural Development Authority
IIR	-	International Institute of Refrigeration
IQF	-	Individually Quick Frozen
MAP	-	Modified Atmosphere Packaging
MDF	-	Medium Density Fiber
pH	-	Potential Hydrogen
Q10	-	Quotient 10
SPSS	-	Statistical Package for Social Science
UK	-	United Kingdom
USAID-KHCP	-	United States Aid Agency- Kenya Horticultural Competitiveness Project
WFLO	-	World Food Logistics Organization

DEFINITIONS

Cold-room: A room in which low temperature of between 8 – 15 ^{0}C is maintained.

Out-grower scheme: Agricultural production carried out on the basis of an agreement between the buyer and farmers/ farm producers.

Pack-house: A facility where vegetables are received, pre-cooled and pre-processed prior to distribution to market.

Pre-cooling Initial cooling to remove field heat from fresh produce.

Smallholder farmer: Smallholder farmers are farmers owning small-based plots of land on which they grow subsistence crops and one or two cash crops relying almost exclusively on family labour.

Cold chain management: System of storing and transporting fresh at recommended temperatures from the point of production to the point of use.

GENERAL ABSTRACT

French bean is one of the major horticultural crops exported from Kenya into International markets. French bean production faces several challenges whose magnitude depend on whether the crop is produced in-house or with an out grower. Unlike with the large commercial growers who have well organized infrastructure to ensure quality food safety of the beans, small scale farmers have always struggled to keep up with the quality expectations of the markets.

This study was aimed at evaluating the performance of solar coolers in enhancing quality and shelf life stability of French beans with an overall of objective of developing a smart solar cooler to replace the use of charcoal coolers. A survey was done to understand the current knowledge and performance of charcoal coolers. Data were collected primarily from a household survey using a semi-structured questionnaire that was administered to 45 farmers that were selected at fixed interval purposively selected. To evaluate the effects of harvesting time and duration before cooling on the post-harvest quality and shelf-life stability of French beans, five harvesting times were evaluated; 7am, 9am, 11am, 1pm and 3pm. The harvested beans were then subjected to five different delay times before cooling; 0hr, 2 hours, 4 hours, 6 hours and 8 hours. The proximate compositions of the fresh French beans samples were determined using standard methods. The microbial quality of French harvested at different times of the day, 7am, 9am, 11am, 1pm and 3pm was also done using standard plate technique. The samples were later graded and packed in modified atmosphere packaging (MAP) bags.

The study revealed that majority (80%) of the farmers adopted evaporative cooling technology using charcoal coolers and stored their produce for one to six hours (68%). Majority of the interviewed famers (67%) harvested between 0 to 5 tons of French beans from their farms while only a few (2.2%) obtained yield above the 20 tons mark. Many of the farmers were not members

of farmer groups and as such were not privy to information shared amongst farmers. There was positive correlation ($P \leq 0.05$ r-0.332) between harvesting time and age and also between storage time and gender ($P \leq 0.05$, r 0.367). However, study level ($p \leq 0.01$r -0.383) and harvesting ($p \leq 0.01$ r- 0.444) was negatively correlated significantly with ($p \leq 0.01$) charcoal cooler effectivity. The results showed that samples had the following ranges of proximate parameters: 2.1 -2.4g/100g protein, 0.8–1.0g/100g fiber, 0.8–1.6g/100g ash, 88 –92% moisture, 0.14– 0.15 fat, and 6.1–7.6g/100g carbohydrate and with 3% change in weight for samples harvested late in the afternoon.

The study revealed a significant loss of moisture and weight for every delay in start of cooling resulted in increase of protein by 18%, fat by 24%. Total viable counts (TVC) in these samples showed mean values ranging from 0.7 to 3.3×10^5 CFUs g-1 for total *Enterobacteriaceae*, *Listeria monocytogenes*, moulds and *Staphylococcus aureus*. Of the microorganisms isolated, *Enterobacteriaceae* (71.6%) was the highest, followed by *Staphylococcus aureus* (20.9%), Moulds (7.2%) and *Listeria monocytogenes* at 0.3%. The harvesting time and duration before cooling significantly ($P \leq 0.05$) affected the population of microorganisms with those harvested early in the morning recording the highest population.

The high presence of microbial load in samples harvested early morning can be attributed to poor hygiene of the harvesters and too much leaf wetness in the morning. The weight of the stored produce reduced by 5% and 2.8% after seven hours under conventional field shed and fabricated solar cooler respectively. The volume of carbon dioxide and oxygen released from produce stored in conventional shed and those stored in fabricated solar cooler prototype significantly differed. Higher volume of CO_2 accumulation was detected in produce stored in the conventional cooling method than those stored in the fabricated solar-powered cooler. Further research should be carried out to understand the influence of solar radiation on the development and existence of *Listeria* *monocytogenes*. It was evident that the *Listeria monocytogenes* population decreased significantly with every delay in harvesting, which could also be attributed to dry leaf and pod surfaces. Contamination from the field may be as a result of soil, irrigation water, contaminated harvesting tools and equipment and contamination from harvesters and food handlers. Hygiene practices like hand washing after using the toilet, before handling produce and avoiding touching of face, skin and nose can be useful in reducing contamination from food handlers. Use of gloves to protect hands during harvesting is necessary to reduce contamination.

CHAPTER ONE:
INTRODUCTION

1.1 Background Information

French bean (*Phaseolus vulgaris* L) is a very important export vegetable crop. In total, combined beans volume is more than 60% of total exports from Kenya (USAID-KHCP, 2013). This accounts for more than 60% of the cost of goods sold. In addition, French bean growing in East Africa has generated a lot of employment and wealth creation, especially with small holder farmers who would otherwise be unable to grow other high capital cash crops (Dolan and Humphrey, 2000).

Large supermarket chains have dominated the fresh produce export business from Kenya to the UK. This has resulted in increased flexible contractual arrangements along fresh produce supply chain. Consequently, this has resulted in increased scrutiny to ensure safety and quality of the fresh produce. The contractual arrangements ensure that the risks are transferred to other actors and agencies along the supply chain. Multiple retailers enforce regulations to ensure the quality requirements for United Kingdom are met and they satisfy the new consumer demands. Leading marketing chains link the growers with high quality horticultural produce in Kenyan with the UK retailers. The first chain has independent retailers who are supplied by wholesale markets while the subsequent chain is comprises of large supermarket multiples. The supermarket chains depend on agreements and contracts that outline product specifications and how the products are handled in order to guarantee quality and safety. The supermarket chains account for almost 70% of the exports to the UK (Laguerre *et al*., 2013).

Strict controls along the supply chain are a prerequisite to ensure high quality French beans get to the consumers. The perishability of the produce demands an operative and constant cold chain. Consumers' demand for high quality produce has been the major driving force behind this. Cold storage has increasingly been viewed as an integral part of supply chain. It is recommended that French beans are stored at 7 – 8 ^{0}C if storage is to be done for about two weeks (Snowdon and Ahmed, 1981). Research indicates existing development of cold chains with sophisticated machinery which requires huge investments. Previous researches indicate that there are over 200,000 small scale growers of French beans in Kenya who supply the export market (USAID-KHCP, 2013).

Small-scale mechanical cooling technologies have been developed for storage of fresh horticultural produce. According to Winrock, (2009) on average, such technologies cost about $7000 for a ton of refrigeration capacity. However, majority of small-scale growers do not have adequate resources for these huge investments in the sophisticated machinery. They are therefore forced to go through intermediaries or for them to group themselves to increase their economies of scale. In addition, the long distances between the production and packing sites have been a great challenge as some produce may take up-to 30 hours to be delivered to the packing sites for it to get proper conventional cooling in the pack-house cold-room. These coupled with inadequate infrastructure to run commercial refrigeration systems in the rural areas aggravate produce quality loss and reduction in shelf-life (Anon, 2011).

Over the last two years research conducted in Kenya have contributed to many small-scale farmers adopting the solar power enabled and low-cost cooling chambers that rely on renewable energy. Charcoal cooler is one of the innovations that is locally made for adoption by small holder farmers to ensure yield while awaiting collection by the exporters remain in good quality. Various designs for small-scale evaporative-cooling storage systems have been developed for fresh produce (Kitinoja and Thompson, 2010). The storage system has space sandwiched between walls that are filled with charcoal and is slowly humidified with water. Alternatively, the whole chamber maybe enclosed with a moist rush mat which can maintain an inside temperature between12 and 16 °C, which is almost 10 °C lower than the ambient temperature. Many researchers have reported that majority of small-scale farmers either store their produce under the tree, in farm structures with no adequate supply of humidity and temperature controls while others do not have any cooling structures but rely on other farmers with cooling systems (Olayemi et al., 2010). This study was intended to explore the possibility of using renewable energy to develop a simple solar cooling system that can be used to address the challenges of cold chain management of French beans to maintain quality and shelf stability.

1.2 Problem Statement

French bean is a major export produce from Kenya. It is predominantly grown by smallholder farmers and large-scale farmers. Smallholder farmers are located in various parts of the country, mainly in Central, Eastern and Rift Valley regions of Kenya. Smallholder farmers are mainly contracted by the exporters to grow the produce. Large scale farmers usually have sophisticated cold chain management infrastructures, unlike the smallholder farmers who usually make use of rudimentary means to manage cold chain, thereby struggling to keep up with the quality expectations (Kitinoja, 2013; Muriithi *et al*., 2011). Small-scale bean growing in Kenya is quite dispersed, from Mt. Kenya, Rift Valley, Eastern and Central region. Some of the out- grower production sites are far away from the processing sites, sometimes as far as 300km away from the processing/packing site. Due to the long distance between the growing site and packing site, the time taken from harvesting to proper conventional cooling in the pack-house cold-room normally varies, this time can be as short as 30 minutes for in-house production and as long as 30 hours for out-grower production. Temperatures in producing areas also vary with average temperatures getting to 33ºC in the day in some months. This kind of temperature has significant impact on produce quality. Despite the development of small-scale mechanical cooling technologies to address quality and safety issues, the high costs to install a refrigeration system by small scale farmers, long distances between the production and packing sites and poor infrastructure to run commercial refrigeration systems hinder adoption of cold chain management. Lack of adequate empirical information on local cooler especially with regards to impact and efficacy has hindered adoption of this relatively cost-efficient technology.

1.3 Justification of the study

Losses due to post harvest diseases and other factors are estimated to be between 30% to 40% all over the world (Gustavsson *et al*., 2011). Poor cold chain management, inappropriate packaging and handling, and shortage of information on quality and safety of perishable produce results in huge post-harvest losses. This leads to loss of market value, increase in food safety risks and reduced income for the growers (Kitinoja *et al*., 2011). In developing countries, physical damage and moisture loss which occur between the grower and the market are responsible for these losses (Kader, 2005).

French bean (*Phaseolus vulgaris L*) is a key export vegetable from Kenya into United Kingdom and the European Union (Tesco 2004; Jaffee and Masakure, 2005). Other emerging markets for Kenyan French beans are Saudi Arabia and South Africa (HCDA, 2003). French bean is grown both in large scale by the well-established commercial farms and also by small scale farmers with limited resources. To maintain such markets that demand high quality produce, tight controls and uninterrupted cold chain management is crucial (Okello and Swinton, 2006).

Those who want to cut costs should consider adiabatic saturation because it is designed without a refrigerant, condenser, pressurized pipes to provide comfort cooling. The materials are low-priced and also consume less energy. Previous researches have shown that local resources such as bricks and charcoal can be used to construct low-cost cooling chambers that reduce and maintains temperature and humidity within the chambers (Odesola and Onyebuchi, 2009). Temperatures inside such cooling chambers are maintained at 12 and 16 °C while relative humidity maintained at 95%. This will effectively address post-harvest deterioration of French beans through reducing respiration, transpiration and ethylene production rates. In addition, such cooling chambers can be used by all the producers as the chambers can be designed for 1-ton capacity. This reduces investment and running costs hence extra income to supply chain actors.

1.4 Objectives

1.4.1 Main objective

The main objective of the study was to develop a smart prototype solar-powered cooler to replace use of charcoal coolers in maintaining quality and shelf life stability of French beans along the supply chain in Kenyan.

1.4.2 Specific objectives

i. To assess the level of awareness and use of charcoal coolers by smallholder farmers.

ii. To evaluate the effects of harvest time and duration before cooling on physiochemical and nutritional quality of French beans.

iii. To evaluate the effects of harvest time and duration before cooling on microbial quality of French beans.

iv. To develop and test a smart prototype evaporative solar cooler based on existing technologies for improved post-harvest quality of French beans during field storage.

1.5 Hypothesis

i. The current level of awareness of small-scale farmers on cool chain management and performance of charcoal coolers in maintaining quality of French beans in low.

ii. Harvest time and duration before cooling has influence on the physiochemical and nutritional qualities of French beans.

iii. Harvest time and duration before cooling has influence the microbial quality of French beans.

iv. A fabricated solar-powered evaporative compression cooler can be used to effectively maintain quality of French beans during field storage.

CHAPTER TWO:
LITERATURE REVIEW

2.1 Overview of French bean Supply Chain for Export Markets

Kenya supplies high-value horticultural products in international markets. The country's main exports include cut flowers, French beans, avocados, Asian vegetables, runner beans, mangoes, mange touts, okra, chilies, and aubergines (HCDA 2007). Cut flowers account for the greatest proportion of horticulture exports and is closely followed by French beans. Kenya is known to produce high-quality French beans in the world and normally in order to improve economic value of French beans value addition and pre-pack sales are done (Narrod *et al*., 2009).

French bean requires great handling to maintain high quality before the products gets to the consumers. Speed and efficiency of operations are a prerequisite during production, transportation, storage or any other process (Okello *et al.*, 2007). To retain quality, a 'cold chain' is a must-have system to control temperature at all points of the supply chain and consumers are able to efficiently receive the produce in prime conditions to guarantee premium prices. It is for these reasons that there is differentiation in responsibilities along the supply chain with large-scale commercial producers control export markets while other firms manage the production, exportation and freight services (Laguerre *et al*., 2013).

According to Kitinoja (2011), at the production level, producers are required to attain high yields of uniform-quality produce. There is need for utilization of primary inputs in a similar way among producers. Most of the large-scale producers are able to follow the guidelines since they have resources to invest in the infrastructure. However, with increasing numbers of small-scale growers in the export trade, challenges have arisen due to inadequate resources that limit their power to invest in infrastructure. Small and medium-sized farmers rely on intermediaries/ agents such as cooperatives, assemblers or large-scale producers to access the export market by bulking the volumes to create exportable volumes. Mostly, these agents rely on contracts with the small and medium-sized farmers. The contracts not only specify produce quantity and production consistency but also the quality and handling procedures. There are over 200,000 small scale and medium-sized growers of French beans in the country.

French beans export market faces two major challenges; an assured freight space on aircraft and temperature-controlled conditions that ensures the produce is fresh throughout the supply chain (Zylberberg, 2013). Unlike large scale exporters, small and medium-scale producers do not have much control over freight space, since they lack the capacity to negotiate guaranteed space on aircraft, since they can rarely fill it with their own produce. They lack the capacity to invest in cold-chain management systems. In addition, cold chain/ temperature abuse is another key challenge facing out grower production of beans. In addition to these challenges, the recent EU 669 Regulations on MRLs on beans and peas that put Kenya on the red alert have been a major concern. These challenges have made very many small-scale farmers to opt out of the French bean growing business (Yabs and Awour, 2016; USAID-KHCP, 2013; HCDA, 2007).

2.2 Spoilage Factors in French Beans and Other Horticultural Produce

Horticultural products continue to metabolize after harvesting during storage, packing, distribution and marketing. Respiration, enzymatic breakdown, pathogenic contamination and degradation cause breakdown of nutrients into simpler compounds that damages the quality and quantity of the produce. Microbial spoilage due to bacteria or fungi results in molds, rots, and water loss through wilting, shriveling or darkening is generally caused (Warriner, 2005).

French beans are contaminated by many spoilage microorganisms at harvest mainly due to contact of the produce with soil or water. Other important sources of contamination are from the air and from handlers. Some species of microorganism will pass the protective cover of the plants thereby causing spoilage; the rest of the spoilage organisms will gain entry through natural openings and wounds (Jay, 1996). Inherent attributes of French beans such as high moisture content and neutral pH, make it susceptible to many spoilage organisms such as bacteria and fungi. External factors such as location, environment, hygiene, handling and storage conditions after harvest will dictate the numbers of microorganisms (Tournas, 2005). Bacteria species of concern in French beans include *Salmonella* spp., *Listeria monocytogenes, Escherichia coli*, and *Shigella* spp. Viruses and parasites have also been reported on French beans (Ramos et al., 2013).

Spoilage processes for fresh French bean through metabolism depends on temperature such that the higher the temperature, the faster the rates of metabolism (Abadias et al., 2008). Generally, post-harvest metabolism rate doubles for each 10°C increase in temperatures. This is known as the Q10 quotient. This means that shelf-life of French beans can be doubled by lowering ambient temperatures by 10°C (Ragaert et al., 2007).

Care needs to be taken as low temperature may cause chilling injury to fresh produce. Chilling injury has been reported for most tropical and sub-tropical produce stored below 10°C. Fresh vegetables perishables will freeze when stored below -1°C (Ragaert *et al*., 2007). Cooling as an intervention reduces metabolic, respiration, transpiration rates, microbial growth, reduced ethylene production, increased resistance to ethylene action, and reduced browning and delayed textural, flavor and nutrients deterioration.

2.3 Post-Harvest Handling of French Beans

2.3.1 Post-harvest handling and cold chain management of French beans

To address spoilage, cold chain management is a must have system along the supply chain (Narrod *et al.*, 2009). A cold chain is defined as a continuous handling of perishable produce within temperatures lower than the ambient temperature (Kitinoja, 2013). This is recommended to start from harvest, during field storage, during transport, and assembling, pre-packing, processing, storage to marketing. Cold chain covers the movement of fresh produce from the field up to the whole postharvest chain. This includes packing, cooling of fresh food products and cold treatment during processing, cold storage, distribution and marketing while cold chain logistics covers the preparation and management of the relations and transitions between the sectors mentioned above to ensure that food is kept at ideal temperature to ensure and safety in order to reduce economic losses (Kohli 2010; Muriithi et al., 2011).

Infrastructure used for cold chain management range from simple to complex cooling equipment The cold chain is recommended by organizations, International Institute of Refrigeration (IR), World Food Logistics Organization (WFLO) and Global Cold Chain Alliance (GCCA). The infrastructure needed and cold-chain management skills are inadequate in developing countries (Kitinoja, 2013).

Several options and technologies are available for bringing-out cold conditions for food along the supply chain (Kitinoja, 2013). These technologies vary from relatively simple and inexpensive systems to more sophisticated and complex systems. It’s recommended to pre-cool products immediately after harvesting (Álvares et al., 2007; Brosnan and Sun, 2001). Ice, forced air, hydro-cooling and vacuum cooling are some of the technologies used for pre-cooling. Cooling systems commonly used during storage include mechanical refrigeration systems, evaporative cool chambers, blast freezers, individually quick frozen (IQF, freeze dryer among others. Ice trailer mounted refrigeration systems, insulated packages have been used during transportation (James, 2013; Kitinoja and Thompson, 2010).

Other methods can be applied to improve efficiency of evaporative cooling systems. For instance, produce harvested early in the morning is put in the cooling chamber at a lesser temperature when compared to produce harvested during the day when the time ambient temperatures high (Paul, 1999). In addition, placing the produce under shade after harvesting will ensure produce is at reduced temperatures (Woolf and Ferguson, 2000). To keep air inside the chamber lower than the ambient daytime temperatures, night air ventilation of the chamber at the basement of an insulated storage structure should be opened then closed during the day. (Seppanen *et al*., 2003). Finally, natural underground cooling in root cellars, high altitude cooling may also be used to lower produce temperature.

2.3.2 Post-harvest handling and immediate temperature reduction of perishable produce

Vegetables require low temperature storage conditions to prolong shelf life through reduction of microbial and enzymes activity, and chemical and biological reactions. Low temperature during handling and storage protects quality attributes such as nutrient content, texture and flavor. The low temperatures are achieved through pre-cooling, cold storage and chilling; freezing is not recommended on fresh French beans (Saravacos and Kostaropoulos, 2002). Refrigeration is recommended during transportation, delivery and home storage of French beans. Ammonia absorption, evaporation of cryogenic fluids, mechanical compression and ice have been used to reduce temperature.

Fresh produce starts to deteriorate immediately after harvest (Ragaert *et al.,* 2007). Perishable produce continues to respiration even after harvest thereby breaking down sugars, starches, and moisture with no replenishment by the plant. This results in generation of CO_2, other gases and heat. Delay in removal of heat accelerates heat production, resulting in a further rise in temperatures of the produce. At the same time, there is enhanced loss of moisture and growth of molds. In addition, nutritional value of the produce vanishes, and the produce is considered to have lost its freshness and quality. Quick reduction and maintenance of produce temperature at lower levels is essential. Therefore, pre-cooling is a prerequisite for maintaining quality, especially for produce that respire rapidly. In addition, harvesting before sunrise maintains quality of products since time of harvesting also influences quality. According to Watada *et al.,* (1996) immediate cooling after harvest can prolong commodity shelf life and quality

Pre-cooling immediately the produce is harvested is recommended and is usually done by putting the vegetables into contact with cold water (Álvares *et al.,* 2007; Brosnan and Sun, 2001), which results in rapid cooling of the product. Increasing the relative motion of French beans and water speeds up the cooling process, due to the resulting high heat transfer coefficients at the water/solid interface. Prior to processing, hydrocooling is done on most fresh produce and the water used for hydrocooling should be chlorinated to inhibit microbial growth (Seymour, 1999).

2.3.3 Postharvest handling, hygiene and sanitation for fresh produce

Fresh and minimally processed produce such as French beans can be agents for the transmission of bacterial, viral and parasitic foodborne infections such as *Listeria monocytogenes*, *Salmonella*, and *Escherichia coli* (Abadias *et al.,* 2008). Infection of fresh produce by the pathogens can occur before harvesting, at harvesting, or even during postharvest handling. Increase in occurrence of foodborne diseases caused by *Salmonella, E. coli,* Norwalk-like, hepatitis A, *Cryptosporidium*, *Cyclospora* among others have been reported (Tauxe *et al*., 1997; Abadias *et al.,* 2008). Since vegetables are marginally processed or may be consumed in their raw form, they pose food safety risk because they can be contaminated by fecal material and soil on the farm.

The UK supermarket chains have imposed stringent food safety standards for French beans imports from Kenya (Narrod, 2009). Some of the standards are third party certification from GlobalG.A.P and British Retail Consortium (BRC), food safety protocols and a Phytosanitary certificate from a competent authority. Traceability requirements should be able to identify the primary producers and agents that handle and ensure hygiene practices are all strictly monitored during growing, harvesting up to packaging. Hygiene standards demand that a toilet, a unit for pesticide storage and hand washing facilities should be in place both at the farm and at the grading shed. Test for water and soil need to be done at least twice every year and results needs to be communicated to the supermarkets. Proper records should also indicate the quality of primary inputs used, that is, pesticides, water and soil. To ensure compliance to the hygiene standards, supermarket chains in the EU monitor the exporters, who in turn are expected to monitor growers. In addition to this, the supermarket chains have agents who carry out direct monitoring at the farm level (Narrod, 2009).

At the exporters' pack houses, prerequisite programs and good manufacturing practices (GMPs) must be in place. The standards require workers to wear protective clothing, to sanitize their hands at regular intervals, to randomly swab workers' hands and test for pathogens, and to properly label containers used at various stages of processing (Narrod, 2009).

2.3.4 Post-harvest handling and use of sanitizer addition when cooling

To eradicate contaminants and microorganisms that are responsible for quality deterioration and decay, washing should be done in liquid chlorine and sodium hypochlorite solutions.

Decontamination procedures are used to decrease the microbial load in fresh produce (Kader and Rolle, 2004; Rico et al., 2007). Chlorine is commonly used at levels of 50-200 ppm for about 5 minutes (Rodger et al., 2004). Use of chlorin at the right concentration is capable of inactivating bacterial pathogens in water and reduce cross-contamination. Acidic solutions enhance the efficiency of chlorine. However, they are used at higher pH levels ranging from 6.0 and 7.5 to lessen corrosion (Beuchat, 2000). Notwithstanding the benefits of chlorine-based sanitizers, free chlorine has been associated with carcinogenic halogenated disinfectant by-products (DBPS) in water (chloramines and trihalomethanes) (Wei et al., 1999). This has resulted in prohibition of use of chlorine on cut-fresh produce in EU countries.

According to Rico and others (2007), chlorine-based sanitizer alternatives include chlorine dioxide, organic acids, hydrogen peroxide, calcium-based solutions, ozone, electrolyzed water, natural antioxidants among others. Chlorine dioxide has antimicrobial activity and a higher oxidation capacity than chlorine and does not react with N-containing compounds to form chloramines compounds (Rico *et al*., 2007).

Acids such as lactic acid, citric acid, ascorbic acid, acetic acid and tartaric acid have antimicrobial activity against psychrophilic and mesophilic microorganisms in fresh produce (Bari *et al.*, 2005). Most of the organic acids also act as oxygen scavengers. Hydrogen peroxide is an oxidant and has the ability to produce other cytotoxic oxidizing agents such as hydroxyl radicals therefore it has both bactericidal and inhibitory activity (Juven and Pierson, 1996).

Calcium based solutions prolong shelf-life of fruit and vegetables since the element promotes development of vegetable cell wall integrity by interacting with pectin to form calcium pectate (Grant*et al.,* 1973). In addition, calcium-based solutions reduce chlorophyll and protein loss and inhibit plant tissue senescence. Ozone, usually applied to vegetables as ozonated water, is a strong antimicrobial agent with high permeability and reactivity and is non-toxic (Kim*et al.*, 1999). Electrolyzed water, a bactericidal agent is more effective than chlorine due to a high oxidation reduction potential (Bari *et al.,* 2003). Natural preservatives, mainly from plant secondary metabolites in essential oils and phytoalexins have antimicrobial effect, inhibit spoilage and reduce oxidative processes.

2.4 Quality Assessment of French Beans

Post-harvest handling of French beans may cause physiological effects, such as increased ethylene production, increased respiration, increased transpiration, susceptibility to microbiological spoilage, loss of chlorophyll, membrane deterioration, changes to pigments, acidity loss, increased sugar level, tissue softening (Kitinoja et al., 2010). The quality of French beans comprises sensory, nutritional and functional properties.

2.4.1 Physiochemical quality of French beans

Most studies try to bring out the relationship between parameters as colour and texture, through sensory assessment or by using apparatus such as texturometers, colorimeters, image analysis software or gas chromatographs. Other quality parameters like flavor and taste are mostly assessed using sensory analysis as objective techniques are yet to be adopted. For the consumers, all quality attributes are integrated, that is, appearance, texture, flavors and odors. In terms of chemical composition, quality of French beans is given in terms of nutritional composition or phytochemicals levels. The most important phytochemicals are antioxidants and their levels indicated by the levels of ascorbic acid, carotenoids, polyphenols, among others (Rico *et al.,* 2007).

In human, French bean pods contribute the dietary Calcium requirements (Grusak et al., 1996). Various factors such as genotypes, and environmental conditions and soil Calcium concentration influence the availability of Calcium in the pods (Quintana et al., 1999). It has been observed that lower temperature accompanied by less soil moisture is linked to lower Calcium concentration due to low pressure in the roots. Inadequate supply of water in dry areas may lead to lower concentrations of calcium. Calcium is quite immobile and can only move in the presence of water. According to Grusak and Pomper, (1999) concentration of Calcium in pods decreases with enlargement of pod diameter due to less density of stomata in the pod and an increased relative humidity. Pod yield and concentration of Calcium varied with different cultivars for instance according to Muchui et al., (2008) there were differences between newly released varieties and local cultivars in Kenya. There is negative relationship between the N content in the pod and Calcium concentration in the nutrient solution supplied to the French bean plants (Favaro et al. 2007)

French bean provides many vitamins, minerals, magnesium and phosphorus (Silbernagel et al., 1991; Grusak et al., 1996; Moraghan, 1994). It's been reported that in comparison to common beans, French bean contains higher quantities of vitamins A and C, Calcium, and fiber content but less starch and protein (Sotelo et al. (2003). However, the protein content decreases between pod developments and senescence stage (Stolle-Smits et al., 1999). French bean pods are richly embedded with protein, folic acid, minerals dietary fiber and health promoting antioxidants such as flavonoids and poly-phenolics. By enhancing nitrogen uptake by French beans, we improve the concentration of protein within the pods (Ahmed et al., 2010). However, the concentration of protein and minerals in pods is affected by cultural practices such as fertilizer application and plant population densities (Abubaker, 2008). It has also been reported that yield and quality of French bean is influenced by both macro and micronutrients and biofertilizers (Salinas-Ramírez, 2011). Researchers Hodges, (2004; Alhag and Hussein, (2014) reported that planting season also had significant effect on various qualities of French beans, and this may vary depending on the environments.

2.4.2 Microbiological quality of French beans

Bacteria, yeast and molds are always present in fresh vegetables and the population depends on vegetable type, environmental conditions, season, agronomic conditions under which vegetables are grown (Francis et al., 1999). The availability of the microbial flora within the vegetables depends on ambient condition at harvesting, presence of contaminants on the product, postharvest handling, and natural variability. Microorganisms decrease the product shelf-life and may cause foodborne diseases (Rico et al., 2007).

Analyses of microbes in French beans have shown that they contain high levels of bacteria and molds. Some of the microbes within the pod can exceed 1 X 10^7 CFU/gram and still may not affect appearance of the produce. With respect to bacterial growth and multiplication, pods have risk just like most fresh produce since the production conditions are conducive for bacterial proliferation. *Salmonella* species, *Listeria monocytogenes*, *Staphylococcus aureus*, *Bacillus cereus*, and *Aeromonas hydrophila* and *Klebsiella pneumoniae* have been isolated from fresh vegetables and are of concern in French beans. Export of French beans follows a complex path from farm-to-fork. Contamination of pods with these microorganisms occurs at any one of these stages. Infection can be introduced through irrigation water, poor sanitary conditions during production, harvesting and packaging practices, improper packaging or mishandling by consumers.

2.4.3 Sensory quality of French beans

From consumers' point of view, product appearance is the most important quality criterion (Kays, 1999). Color is considered as an important component of appearance, food choice and food preference along with texture, characterizes the freshness of most vegetables due to chlorophyll degradation and browning. Browning of fresh produce reduces acceptability, reduces shelf-life and marketability of fresh-cut vegetables (Rico et al., 2007).

Acceptable French bean qualities include well-formed straight pods, bright colored pods free of blemishes, tender and firm pods (Cantwell and Suslow, 1998). These qualities have direct influence on the accessibility to fresh market. Consumers prefer bean pods with slight lumps showing they are tender with young seeds and those that break easily when the pod is bent. Different regions prefer different quality and type of French bean those produced Eastern Africa are round and thin and best suited for EU markets. French bean improvement in East Africa region has focused on bushy and climbing French bean cultivars with a high harvestable yield. However, obsession with increase in productivity may lead to development of cultivars that mature late or an increase in pod size that are of less quality (Myers and Baggett, 1999).

2.5 Evaporative Cooling Systems Used For Vegetables

There are two types: direct and indirect cooling systems. In direct evaporative cooling, air passes across the humidifier into the cooling chamber, while the heat exchanges pre-cools the air before passing through the cooling pad (Jain, 2007; Xuan et al., 2012). There are two types of direct evaporative cooling system i.e. active and passive evaporative cooling systems. In active evaporative cooling systems, the ambient air is driven through the wet pad into the system by the fans (Ndukwu et al. 2013) while in passive evaporative cooling systems, the cold air is driven naturally into the system through circulation. Passive systems apply in areas characterized by windy movements and low-pressure head.

Evaporative cooling acts by lowering the temperature and at the same time increases the relative humidity of the ambient air in direct evaporative cooling systems. Low temperature and high humidity are required in fruit and vegetable preservation in order to slow pathological activity and prolong its shelf life (Adebisi et al., 2009). Any system that lowers the temperature and at the same time increases relative humidity in comparison with ambient temperature, suppresses enzymatic degradation and respiratory activity of the produce. The process also slows down dehydration, inhibits the growth of molds and bacteria, reduce ethylene production or lessens the reaction of the product with ethylene and other metabolic activities (Boyette et al., 2013).

2.6 Solar Collectors Used In Food Cooling Systems

Different solar thermal collectors have been developed. These include the flat plate collectors with a shallow box mounted on the roof and provide heat through sun energy, the air collectors that is used in space heating and evacuated collectors reduce the heat loss in the environment (Jiang et al., 2020). Compound parabolic collectors (CPCs) are non-imaging concentrators with ability to reflect to the absorber incident radiation and tracking concentrator collectors (Jiang et al., 20202). Solar energy is converted into electricity through the use of photovoltaic panels. However, conjoining the photovoltaic cells with a solar thermal collector can concurrently convert solar energy into electricity and heat. This type of solar collector is known as PV/T and can be applied in various areas, but the appropriate applications are those that require heat energy in the range of 60 °C to 80 °C (James, 2013).

An absorption chiller system commonly has single, double, and triple effects depending on application needs. The higher the effects, the more cooling capacity can be provided. Single effect absorption chillers are usually sufficient for small applications in a typical home. The basic components for the absorption chiller are the generator, condenser, evaporator, absorber, multiple heat exchangers, and pumps. The storage tank is another important component of an absorption chiller system. This tank enables climate control operation to be continuous during periods when solar energy is not available (evenings) or when it is not sufficient to drive the cycle. The size of the storage tank will depend on the safety factor adopted to extend the operation into these periods (Jain, 2007).

2.7 Gaps in Knowledge

Kitinoja and Thompson (2010) and Winrock International (2009) have documented basic recommendations on precooling and cooling with regards to infrastructure investment costs and running costs for small, medium and large-scale operators. Mechanical systems are challenged by the fact that fuel costs to run the systems are high, thus making it cost-effective for high-value products. To address this, evaporative cooling systems may be used with other systems such as refrigeration systems, night ventilation, among others. This will lower the cost of cooling and precooling. Such systems when developed may be implemented in regions where electricity infrastructure is not adequately developed. There lacks adequate empirical information on the feasibility of combining several cooling systems. This research will address this research gap and offer solution to use of renewable energy in cooling and precooling.

CHAPTER THREE:
LEVEL OF AWARENESS AND EFFECTIVENESS OF CHARCOAL COOLERS IN MAINTAINING THE QUALITY OF FRENCH BEANS

1.6 Abstract

French bean requires great handling to maintain high quality before the products gets to the consumers. Speed and efficiency of operations are a pre-requisite during production, transportation, storage or any other process. This study aimed at assessing current knowledge and performance of existing charcoal coolers in improving the overall quality and shelf-life of French beans. Data was collected primarily from a household survey using a semi-structured questionnaire that was administered to 45 purposively selected bean farmers. Majority (56%) of the interviewed farmers allocated between 51-75% of their land to French bean production. The study revealed that majority (80%) of the farmers adopted charcoal cooling method and stored their produce for one to six hours (68%). However, most of the farmers did not belong to farmer groups and as such were not privy to information shared amongst farmers. Farmers' level of education level had positive ($P \leq 0.05$ r-0.332) influence on use of cold storage facility. However, level of education ($p \leq 0.01$, r-0.383) and harvesting ($p \leq 0.01$ r- 0.444) was negatively correlated significantly with ($p \leq 0.01$) charcoal cooler effectivity. To sustain the use of cold storage facilities and technologies the government should establish a community based cold storage facility that can be accessed by the farmers to ensure availability of sufficient quantities and ensure farmers continued access to information through the horticultural companies. In addition, farmers should be encouraged to join farmer groups to collectively gain from knowledge and technology transfer.

Key words: Charcoal cooler, cold storage, Pre-cooling, French beans, post-harvest practices

3.2. Introduction

French bean (*Phaseolus vulgaris L)* is considered one of the most important vegetable exports from Kenya into the United Kingdom and the European Union. Strict controls along the supply chain are a prerequisite to ensure high quality French beans get consumers. The high perishability of the produce demands an effective and uninterrupted cold chain. Once harvested, fresh foods break down and utilize their nutrients from harvesting to packing and while under distribution and marketing. The higher the temperature the faster the losses through colour, flavor, nutrients and textural degradation. It's been reported that when temperature is maintained at 10^{o}C (Q 10 quotient) less than the ambient conditions, the shelf life of the commodity can be doubled (Kitinoja, 2013). Apart from physiological deterioration, these products play host to micro-organisms which can cause rotting and decays.

Mechanisms to reduce losses associated with increased temperature in order to maintain both visual quality and nutritional value have been developed to reduced loss (Kitinoja, 2013). The horticultural sub-sector faces, the major one being high post-harvest losses. The major contributor to these losses is temperature (Vorster *et al*., 1990). The speed at which the perishables goods decay may double or triple with every 10 ^{o}C increase in temperature (Kader 2005). A cold chain for fresh commodities that easily perish can be defined as the continuous handling of the product at low temperatures during the postharvest process such as harvesting, collection, packing, processing, storage, transport and marketing until it reaches the final consumer (Kitinoja, 2013). Cold chain management should start at the time of harvesting and must consider the time of harvesting (Kathryn and James 2004).

Temperature abuse from the farm predisposes the produce to faster deterioration. In smallholder farms, the temperature abuse temperature misuse is attributed to factors such as lack of knowledge on good harvesting practice and postharvest. Cold chain system has been supported by various organizations including International institute of refrigeration (IIR), the World Food Logistics Organization (WFLO), and the Global Cold Chain Alliance (GCCA). There are various options and technologies for providing cold conditions for food commodity handling, storage and transport. Evaporative charcoal cooler is designed to offer an environment with both lower ambient temperature and a higher level of relative humidity (Nanguwo, 2000). It employs the principle of a porous structure to which water is added and as air flows within the wet wall and the air temperature is decreased due to the loss of heat through evaporation.

The temperature is normally lowered by about 5 to10^{o}C, depending on the relative humidity of the ambient air. To address this challenge, a lot of research and innovation over the last two years in Kenya have resulted with small scale farmers increasingly adopting use of low-cost cooling chambers that use renewable energy (Toivonen *et al*., 2014). One of the most noticeable innovations is the use of locally made cold store referred to as “charcoal cooler” for use by small holder farmers to keep their produce awaiting collection by the exporters. The objective of this survey was to understand current knowledge and extent of use of cold chains interventions in French bean production in Kajiado and Narok Counties

3.3 Materials and Methods

3.3.1 Selection and description of the study site

The study was carried out in two counties of Kajiado and Narok. Kajiado County is located in the southern part of Kenya. It is situated between Longitudes 36^{o}5’and 37^{o}5’East and between Latitudes 1^{0}’ and 300’ South. Narok County is situated in Kenya along the Great Rift Valley. The temperature range is between 12^{o}C- 32^{o}C and average rainfall range of 500 to 1,800 mm per annum. Its geographical coordinates are 1° 5’ 0” South, 35° 52’ 0”. A list of farmers who participated in the project was obtained and this formed the sampling frame. A total of 45 households were randomly selected and interviewed. This area was purposively sampled because of the large numbers of small-scale producers who mostly supply exporters. The prevailing weather and climate in this area is suitable for installation of coolers that use renewable energy.

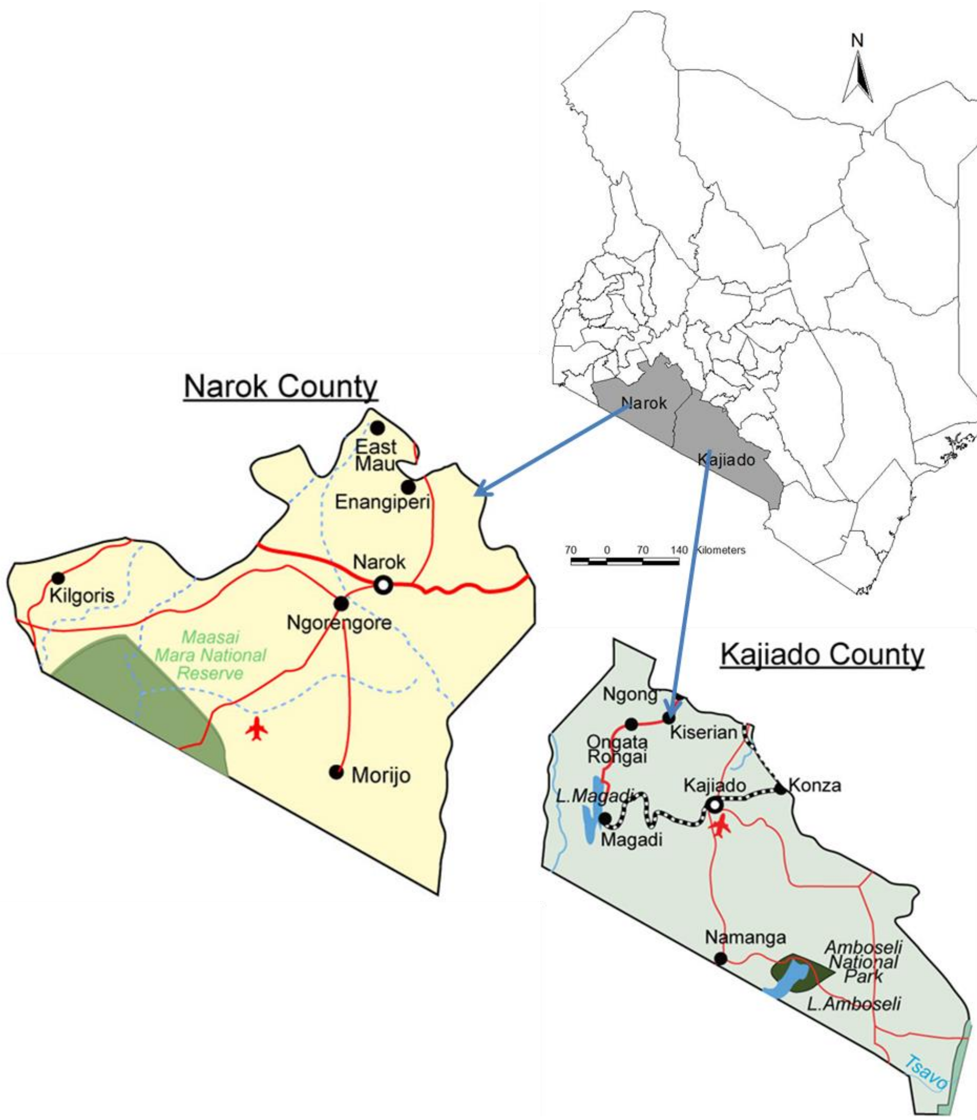

Figure 3. 1: Map of Kenya showing the location of Narok and Kaijado Counties

3.3.2 Sampling technique

Data was obtained primarily from a household survey that targeted French bean producing farmer in both Kajiado and Narok Counties. Farmers were selected through a systematic random sampling procedure. Farmer register from the two counties was used to serve as the sampling frame and each farmer in this list was numbered sequentially. The targeted farmers were selected at fixed interval from the list to come up with 45 farmers from the two counties.

3.3.3 Data collection

Data was collected by administering a semi-structured questionnaire (Annex 1) to collect quantitative and qualitative data. The questionnaire was administered through personal interviews. Data were collected on attitude and extent of use of charcoal coolers, temperature at harvesting and at storage, the type of storage facility, produce storage time, additional data were collected on changes in French bean and washing of the produce and marketing.

3.3.4 Data analysis

Data collected was checked and open-ended questions were coded before data entry. Data were analyzed using the Statistical Package for Social Science (SPSS) Version 20 by computing descriptive statistics including frequencies, percentages, means and averages.

3.4 Results

3.4.1 Household demographic characteristics of the farmers

Results indicate that most of the respondents were male farmers (75%) across the counties (Table 3.1) and the proportion of male farmers was also higher in both Kajiado (71%) and Narok (86%). Majority of the interviewed farmers were between the ages of 41 to 50years (33.3%), however, the age ranged from 19 years to over fifty years. Though not statistically different, the farmers In Narok were slightly older than those in Kajiado. The distribution of sampled farmers in term of marital status, nearly all the farmers were married except one who was a widow. The distribution of sampled farmers in terms of education has shown that majority of farmers had a basic education

(40%) followed by primary then post-secondary education. The farmers in Kajiado had statistically higher score in education than those from Narok

Table 3.1: Socio-economic characteristics of French bean farmers in Narok and Kajiado Counties

Variable	Description	Kajiado (%)	Narok (%)	Total (%)
Gender	Female	13.3	11.1	24.4
	Male	44.5	31.1	75.6
Age	Over 51 years	8.9	15.6	24.5
	41 to 50 years	13.3	20.0	33.3
	31 to 40 years	13.3	13.3	26.6
	19 to 30 years	6.7	8.9	15.6
Marital status	Widowed	2.2	0.0	2.2
	Married	62.2	35.6	97.8
Study level	Post-secondary	17.8	8.9	26.7
	Secondary	26.7	13.3	40.0
	Primary	17.8	15.6	33.4

3.4.2 Land size and land allocated to French bean production

French bean farmers in the two counties owned land in various categories out of which the majority (44%) owned land between 5 and 10 acres (Figure 3.1). A few farmers owned land less than 5 acres while others owned land above 10 acres. Majority (56%) of the interviewed farmers allocated between 51-75% of their land to French bean production. Farmers in Kajiado County had significantly more land allocated to French bean production than farmers in Narok County.

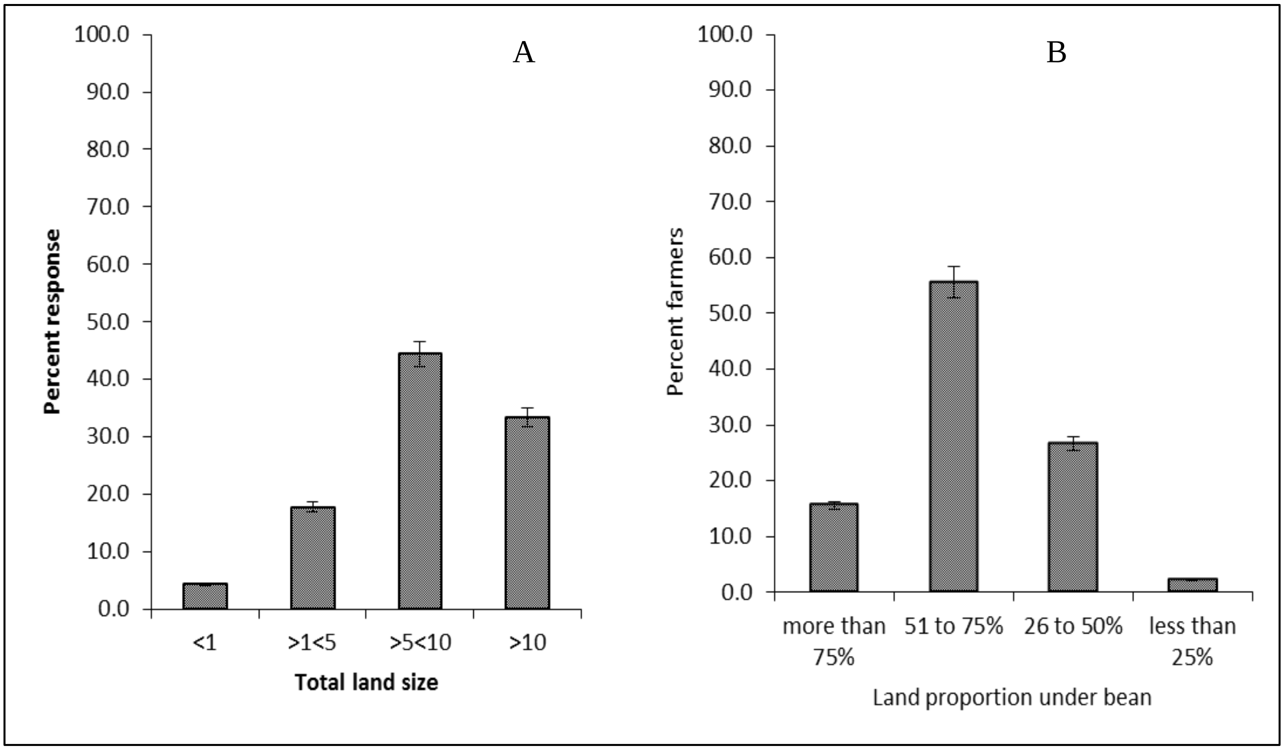

Figure 3.2: Proportion (%) of land owned by the farmers (A) and Proportion of farmers who allocated land to French bean production (B)

3.4.3 Daily farm operations

When the farmers were asked about the person responsible for daily farm operations, majority of the farmers (91%) reported that they were solely responsible for their daily farm operations (Table 3.2). However, a few (9%) employed either on permanent basis or as casual laborers to handle the daily farm operations. Among the few employees, around 50% had post-secondary education while the rest had either secondary or primary education levels. The employees were either salaried employees (50%) casual laborers (25%) or some offered helping hands (25%) to the farmers

Table 3. 2: Characteristics of people responsible for daily farm operations

Description	Category	Frequency	Percentage (%)	Std. Dev
Daily management operation	Farmer	41	91.1	0.31
	Employee	4	8.9	
Education level of employee responsible	Pre/primary	1	25.0	0.95
	Secondary	1	25.0	
	Post-Secondary	2	50.0	
Occupation of employee responsible	Salaried employee	2	50.0	1.50
	Casual labor	1	25.0	
	Not employed	1	25.0	

3.4.4 Season of French been production

Majority (60%) of the farmers interviewed produced French bean two seasons in a year while others (40%) produced French beans in three seasons per year (Figure 3.2). This suggests they had irrigation infrastructure. The study revealed that majority of the interviewed famers (67%) harvested between 0 to 5 tons of French beans from their farms while only a few (2.2%) obtained yield above the 20-tone mark.

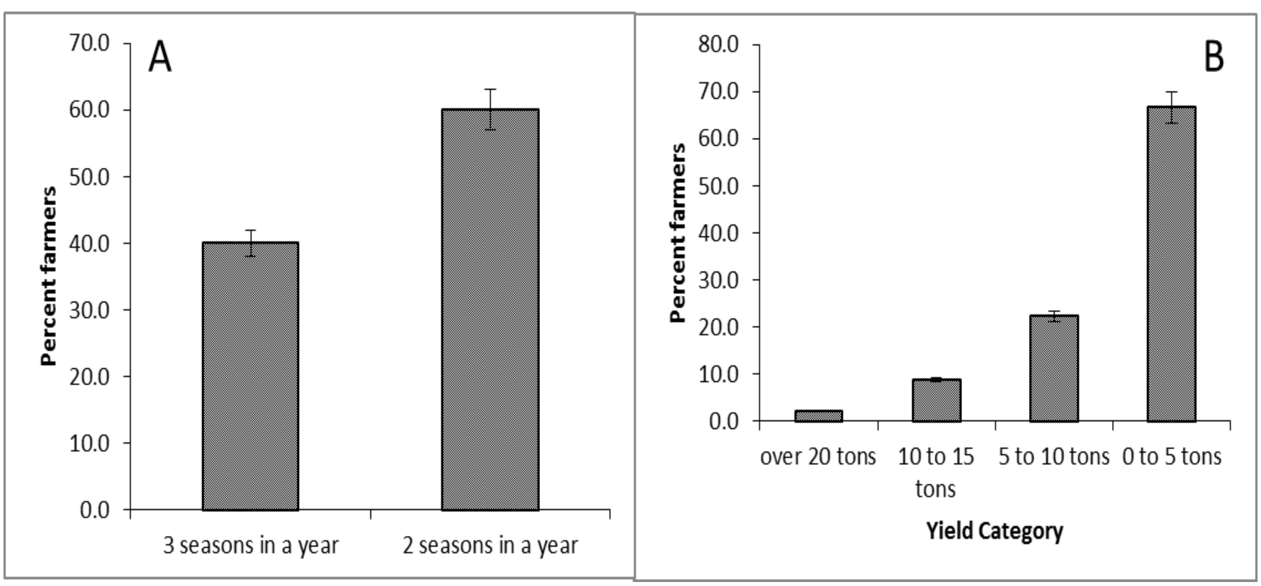

Figure 3. 3: Main seasons of French bean production and yield achieved by the farmers

3.4.5 Key postharvest practices

The table 3.2 shows some of the post-harvest handling activities that were practiced by the farmers in the two counties. Majority of the farmers do not wash the French beans (68%), harvest late when the sun is up (80%), target the highest temperature of 16 – 20^{o}C (76%) and store their produce for longer time (69%). Some farmers, however, stored their produce for less than an hour then delivered them to the buyer (20%).

Table3. 3: Proportion of farmers practicing post-harvest practices on French beans

Description	Category	Frequency	% of responses
Produce washing	Yes	15	33.3
	No	30	66.7
Time of harvesting	6am-9am	8	17.8
	9am-12pm	36	80.0
	12pm - 3pm	1	2.2
Measure Temperature	Yes	9	20.0
	No	36	80.0
Targeted temperature	6^{o}C – 10^{o}C	3	6.7
	11^{o}C- 15^{o}C	7	15.6
	16^{o}C- 20^{o}C	34	75.6
	More than 20^{o}C	1	2.2
Storage duration	less 1 hour	9	20.0
	1 to 6 hours	31	68.8
	6 to 12 hours	5	11.1

3.4.6 French bean qualities demanded by the buyer

Buyers always specify the qualities of the produce they require from farmers (Table 3.4). To achieve the required qualities, the farmers performed certain practices. Majority of the farmers (40%) reported management of pest and diseases, others (24%) reported good fertilizer application as a way of achieving the demanded quality. Other practices performed by the farmers included planting certified seeds, timely irrigation, timely harvesting and grading and proper land preparation.

Table3.4: Proportion of farmers who reported factors considered in meeting the quality demanded by the buyer

Factors considered to meet buyers demand	Frequency	% of responses
Fertilizer application	11.0	24.4
Control of pests and diseases	18.0	40.0
Planting certified seeds	9.0	20.0
Proper land preparation	1.0	2.2
irrigation in time	8.0	17.8
harvesting and grading	12.0	26.7
Total	59.0*	

*****Multiple responses

3.4.7 Farmers' understanding of the quality demands

Many farmers understood the qualities demanded by the buyers (Table 3.5). Some of the qualities mentioned were pests and disease-free products, products with no blemishes, non-dehydrated products, pods diameter 8mm and length of (11-13cm), and well graded pods. Majority (73%) of the interviewed farmers reported pest and disease produce as the most demanded quality by the buyers. Other mentioned products with no blemishes (20%), non-dehydrated produce (15.6%). A few other farmers mentioned pods with 8mm diameter and well graded pods.

Table 3. 5: proportion of farmers who reported qualities of French beans demanded by the buyer

Quality demanded by buyers	Frequency	% of responses
Pest and disease-free products	33.0	73.3
products with no blemishes	9.0	20.0
Non-dehydrated products	7.0	15.6
seed diameter 8mm (11-15cm)	5.0	11.1
well graded seed	4.0	8.9
Total	58*	

*****Multiple responses

3.4.8 Farmers' group membership

The results show that there is low participation in farming groups amongst the interviewed farmers (Figure 3.3). The interviews revealed that most (57.7%) of the farmers were not member of famer groups and therefore were not involved in farmers group activities. Only a few farmers were members (42%) of a known group however, only 24% of these farmers collectively stored their produce in farmer groups. Notably, majority of the farmers reported that they sold their produce through one of the major horticultural companies in Kenya Flamingo Horticulture (Figure 3.4)

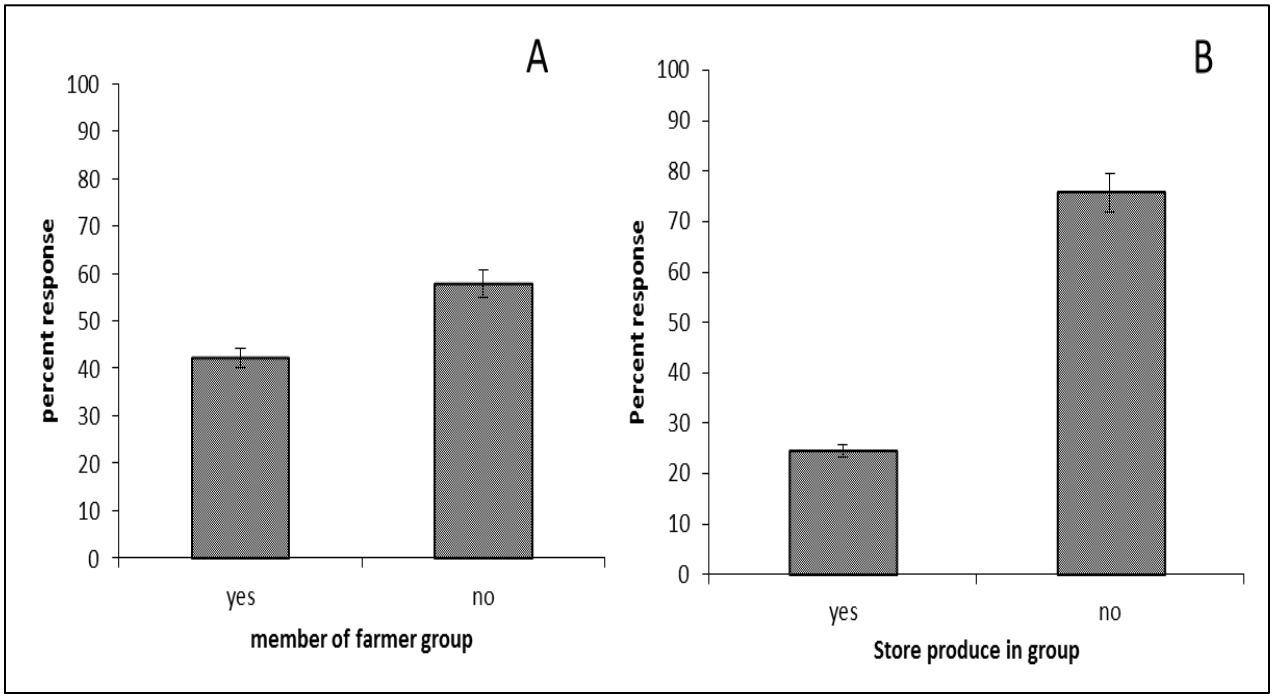

Figure3.4: proportion of farmers who are members of farmer groups and if they stored their produce as a group

3.4.9 French bean buyers

The farmers indicated that among the buyers, the majority (96%) of their produce were supplied to large exporters while only a few (4%) sold their produce through the brokers (Figure 3.5).

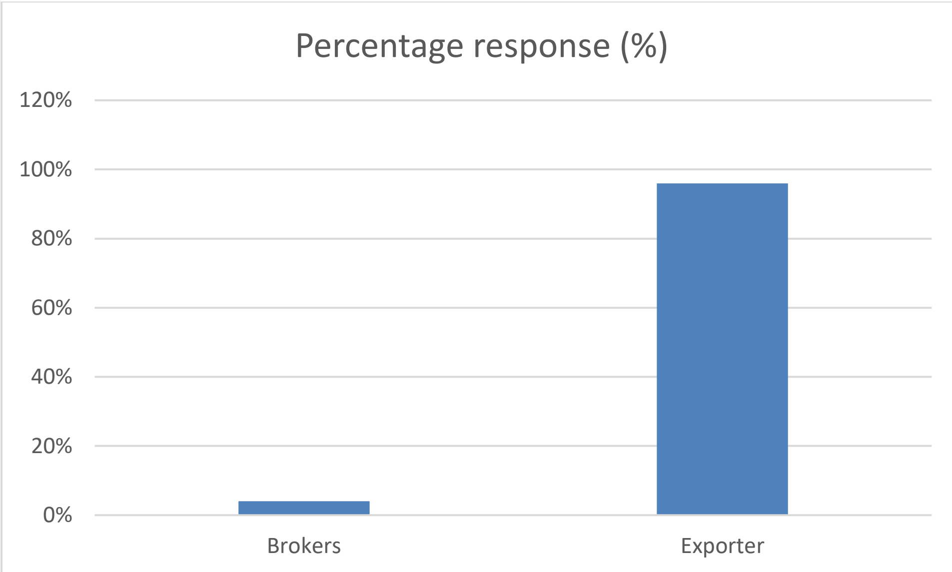

Figure 3. 5: French beans market outlets

3.4.10 Charcoal cooler usage and construction materials

The usage of charcoal cooler among the farmers was common knowledge as majority (80%) of the farmers agreed to have either used the charcoal cooler or borrowed from another farmer while only a few of the farmers had not used the cooler (Table 3.6). The farmers were also asked about the materials they used in constructing the charcoal cooler in terms of the floor, the walls and the roofs. Majority (73%) cemented their floor while other either put concrete floor or wooden planks. All the farmers used iron sheets as the roofing materials while they used the charcoal to construct the wall. However, in terms of humidifier installation, only 31% installed humidifiers while the rest did not.

Table 3.6: Proportion of farmers who have used charcoal cooler and the material for construction of charcoal cooler

Variable	Description	Frequency	Percentage (%)
Have you ever used charcoal cooler	Yes	36	80.0
	No	9	20.0
Floor	Cemented floor	33	73.0
	concrete floor	2	4.4
	wood planks	1	2.2
Roof	iron sheets	36	80.0
Walls	charcoal wall	36	80.0
Presence of humidifiers	no running water	22	48.9
	water	14	31.1

3.4.11 Effectivity of the charcoal cooler

Results in Table 3.7 shows that majority (71%) of the farmers interviewed confirmed that the charcoal cooler was effective as a storage facility while only 11% of the respondents suggested otherwise. In addition, when the farmers were asked how to improve the storage cooler, over 50% of the respondents suggested installation of humidifiers. Others (5%) suggested improvement in air circulation within the coolers while a further 5% suggested installation of cooling system in the roof. Other suggestions included enlargement of the cooler plant, addition of more charcoal, and reinforcing of the wall by using wire mesh.

Table 3. 7: Proportion of farmers reporting effectivity of the cooler and suggested improvement to enhance performance

Description	Category	Frequency	% of responses
Effectivity of the cooler	Yes	32.0	71.1
	No	5.0	11.1
What could be done to improve the cooler	Cementing floor	1.0	2.7
	More charcoal	2.0	5.4
	size enlargement	2.0	5.4
	Wall mesh	3.0	8.1
	roof cooling	5.0	13.5
	air circulation	5.0	13.5
	installing humidifiers	19.0	51.4

3.4.12 Correlation coefficient among demographic characteristics of farmers and various post-harvest practices

Demographic characteristics were correlated with various post-harvest practices (Table 3.8). The relationship between harvesting time and age was a positively correlation ($P \leq 0.05$ r-0.332) while that of storage time and gender was also positively correlated ($P \leq 0.05$, r 0.367). However, study level ($p \leq$ 0.01r-0.383) and harvesting ($p \leq 0.01$ r- 0.444) was negatively correlated significantly with ($p \leq 0.01$) charcoal cooler effectivity

Table 3. 8: Correlation coefficient among demographic characteristics of farmers and various post-harvest practices

	Age	Gender	Marital status	Study level	Harvesting time	Measuring temperature	Targeted temperature	Storage	Storage time	Charcoal cooler	effectivity
Age	1										
Gender	-.017	1									
Marital status	.050	.265	1								
Studylevel	-.114	.116	-.182	1							
Harvesting time	-.332*	-.159	.056	.037	1						
Measuring temperature	.028	.071	-.247	.142	-.215	1					
Targeted temperature	-.072	.079	.066	-.132	.532**	-.273	1				
Storage	-.051	.367*	-.047	.128	-.257	-.057	-.247	1			
Storage time	.065	-.204	-.249	-.171	.147	.186	.336*	-.442**	1		
Charcoal cooler	-.169	.323*	.351*	-.111	-.130	-.129	-.099	.295	-.410**	1	.[b]
Effectivity	.413*	.011	.[b]	-.383*	-.444**	-.071	-.093	.255	-.304	.[b]	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

3.5 Discussion

Demographic and socio-economic characteristics play important role in understanding the differences between farmers and hence explaining their behavior regarding adoption of certain technologies. The major characteristics of farmers covered in the survey were distribution of farmers by gender, educational level, marital status and farmers' age.

Results show that many (76%) of the interviewed farmers were male while females only constituted (24%). This implies that French bean production in the two regions was dominated by males. This may be due to the fact that French bean farming is labor intensive (Usman *et al*., 2016). This contradicts many findings which have reported in most cases women as the leaders in agricultural activities. Gender of the farmers captures the differences in post-harvest handling between female and male farmers with either expected to have higher tendency to carefully handle the produce (Garikai, 2014).

Age is considered a key demographic feature because it determines the quality of work (Babalola, *et al*., 2010). Majority of the farmers were between the age of 41 -50. This implies that many farmers actively involved in agricultural production and therefore there is possibility of high productivity. The study further revealed that majority of the farmers were married and had family responsibilities. These results concur with findings by Adamu (2005) who found that the majority of arable farmers were married and therefore they are enthusiastic agricultural production activities in order to improve the living standard of their households (Siri *et al*., 2012). Older farmers with huge farming experience are expected to easily adopt new technologies and that includes appropriate post-harvest handling technology to reduce losses associated with increased temperature (Martey *et al*., 2012).

The interviewed farmers had different levels of education, majority (44%) attained the basic level of the Kenyan education system. Attaining some level of education enables farmers to make choices based on their decision as well as work together with ease with other farmers (Martey *et al.*, 2012). It is often assumed that educated farmers have better managerial skills and are able to search for appropriate technologies (Siri *et al*., 2011) and would find it easy to invest in post-harvesting technologies to avoid losses (Garikai 2014). Farmers who have attained higher levels of education appreciate and use post-harvest technologies (Babalola, *et al*., 2010). This implies that farmers in the region are open to new ideas and may not necessarily stick to old methods of agriculture. With introduction of a new technology, adoption rate is expected to be high amongst educated farmers

Land ownership and land size are factors often considered important in technology adoption. It has been claimed that farmers with larger pieces of land are more likely to adopt an improved technology compared with those with small farms. Of the sampled respondents' majority were small scale farmers. Land ownership, size and quality positively influence adoption of technology (Abera, 2009). Majority of the farmers did not belong to any farmer group. Farmer group membership helps in accessing information important in production, post-harvest practices and marketing (Garikai, 2014).

According to Ortmann and King (2007) farmers formed cooperatives and farmer group organisations because of promotion of self-help, improving negotiating strength between them and input suppliers and buyers of farm products, assurance of input supplies and markets access. The lack of participation in these farmer groups meant lack of access to information on production, post-harvest handling of French bean and marketing and this may have negative effect on the overall yield achieved by the farmers.

When handling perishable goods like French beans, high standards of hygiene are paramount. However, that appeared not to be the case in the two Counties as majority of the interviewed farmers admitted not to washing their produce. This can be attributed to very stringent rules on post-harvest wash as outlined in the Food Safety Standards that most exporters subscribe to, mainly Global GAP that has strict control on the quality of water that can be used to wash fresh produce, such water must be portable/drinkable quality, a requirement that may not be achieved by most of the small holder farmers. A few of the farmers used chlorine tablets to disinfect water for produce wash. Kader *et al*., (2005) reiterated that good hygiene while handling the produce minimizes contamination hence reduction in post-harvest losses.

Majority of the farmers interviewed harvested French beans from 9.00am to 12 noon others also harvested in the afternoon. The time a farmer decides to harvest may impact positively or negatively to losses associated with post-harvest. Harvesting in the morning when the temperatures are not high results in low post harvest losses. Morning hours is characterized by high humidity and low temperatures with the produce still turgid while in the afternoon the weather is characterized by high temperatures, and high evaporation resulting in less turgid and shriveled produce (Kereth *et al*., 2013). Therefore, more metabolic reactions such as respiration are expected to increase in the afternoon (Mashau *et al*., 2012). The results from the survey show that many farmers stored their produce for between one to six hours. French bean in its harvested form contains high percentage of water and therefore carries out physiological respiration (Idah *et al*., 2007).

As the produce respires and losses water, their quality depreciates as they dehydrate and shrivel. This leads to deterioration during transit and storage, hence the need for minimal storage times. Change in texture, aroma and even spoilage depends on the time the produce is stored (Yahia, 2006). Post-harvest handling and processing of produce has an impact on the biochemical changes, and microbial contamination (Rico *et al*., 2007). To avoid contamination and degradation of the fresh produce, Kader (2005) suggests that reducing potential contamination of the produce during growth, harvesting and up to storage. Conformity to sanitation standards is necessary to limit losses.

Considering majority of farmers have cold storage rooms, storage period of up to 6 hours were reported. Storage period is an important aspect when handling French beans, majority of the interviewed farmers stored French beans for between 2 to 3 hours. It's been reported that longer storage periods result in quality deterioration. Fresh produce like French beans continue to breakdown and utilize their nutrients during the entire chain up to marketing and even sale. This results in rapid loss of the produce through breakdown of nutrients into simpler compounds when the temperatures are high (Gikaria, 2013). Minimizing the storage time at the farm will help in reducing post-harvest losses as suggested by Kader (2005) who argued that as the time the produce stays in the market increase from the time of purchase, its deterioration also increases.

The study revealed that many of the farmers held their produce in the farm for long periods of time before delivery to the respective customers. Kader (2005) reported overheating during storage and transportation results in increased water loss. Availability of optimum temperature and relative humidity is the most important tool for maintaining quality of vegetables (Kader 2003)

Majority of the farmers used mainly cement for floor construction, charcoal for wall and iron sheets for roofing. As suggested by the farmers, increasing the size of the cooler is important. Enough floor space provides instant access to the produce within the room. It is recommended that the floor should be furnished with a proper drain to dispose of waste water from cleaning and condensation. A charcoal cooler employs the principal of evaporative cooling to maintain cool interior temperature for produce preservation. The facility is constructed from an open timber frame with charcoal filled wall which should be continuously moistened. Many of the farmers with cold storage facility did not install humidifiers. As the warm dry air goes through the moist charcoal, water is evaporated into the air resulting into the cooling. This facility works by increasing the air moisture content, preventing produce from drying out then extending the shelf life.

3.6 Conclusion

Small scale farmers of French beans have good knowledge on the use of cold chain management practices along the supply chain in Kenya and they have confidence in the ability of charcoal coolers in managing cold chain of French beans. There is need to encourage the small-scale farmers to organize themselves into groups so as to gain from communal services, knowledge and technology transfer.

3.7 Recommendation

Small-scale farmers should harvest their produce early in the morning before sun heat advances so as to effectively navigate cool chain challenges and maintain quality and freshness of fresh produce.

CHAPTER FOUR:

EFFECTS OF HARVEST TIME AND DURATION BEFORE COOLING ON THE PHYSIOCHEMICAL AND QUALITY AND NUTRITIONAL QUALITY OF FRENCH BEAN (*Phaseolus vulgaris L.*)

4.1 Abstract

Post-harvest management of French beans are critical in ensuring acceptable quality in the market. The time of harvesting and duration between harvesting and cooling are very important. Further, long distances between growing fields and cooling facilities provide challenges to growers. This study was carried out to evaluate the effect of harvest time and duration before cooling on the physiochemical and nutritional quality of French beans. Five harvesting times were evaluated ;7am, 9am, 11am, 1pm and 3pm. The harvested beans were then subjected to five different durations before start of cooling; 0hr, 2hr, 4hr, 6hr and 8hr. The proximate compositions, crude protein, ash content, crude fiber, fat, moisture content and weight loss of the fresh French beans samples were determined using standard methods as outlined in Association of Official Agricultural Chemists (AOAC) procedures. French beans harvested early in the morning had the highest moisture content (90%) while those that were harvested mid-morning had the least moisture content (87%). The results also revealed that French bean samples had the following ranges of proximate parameters: 2.1 -2.4g/100g protein, 0.8–1.0g/100g fiber, 0.8–1.6g/100g ash, 88 – 92% moisture, 0.14– 0.15g/100g fat, and 6.1–7.6g/100g carbohydrate and with 3% change in weight for samples harvested late in the afternoon. The study revealed a significant loss of moisture and weight for every delay in start of cooling while there was marginal increase in protein, fat and ash contents.

Key words: Postharvest quality; shelf life stability; Harvesting time, duration before cooling, *Phaseolus vulgaris* L

4.2 Introduction

French bean (*Phaseolus vulgaris* L.) is a nutritious vegetable rich in vitamin C, and dietary fibers, carbohydrates, proteins and minerals (Kasim and Kasim, 2014). The immature pods, and also dry beans are used as curry and are served fresh in salads but in most cases prepared as cooked vegetables (Kasim and Kasim, 2014). Green beans are harvested at physiologically immature stage when their metabolism and respiration is fast even when the temperatures are low (Babalola *et al*., 2016). Therefore, quality may diminish rapidly, and actions must be taken to avert quality deteriorations. The quality of French beans pods depends on factors like area of production, variety, post-harvest handling, maturity stage, harvesting, cool chain management and storage conditions. Hence, harvesting of French beans at the right is important as it ensures optimum quality and yields. The harvesting stage depends on the intended customer and is primarily determined by the pod diameter. The ideal stage is to harvest when the pods are tender and crispy, and seeds are immature. Harvesting is important at the right time as harvesting either at early or late stage results in lower yields or overgrown pods, resulting in produce rejection.

Like many of the horticultural crops, French beans are perishable and deteriorate in quality very fast after harvest and therefore high post-harvest losses are incurred (Ambuko *et al*., 2003). Delays in between harvesting and cooling can result in direct losses, however, the extent of the losses is subject to the conditions of commodity at harvest and the product temperature, which can be higher than ambient temperature (Kader, 2002). The high perishability of the French beans demands an effective and uninterrupted cold chain process. It is recommended that French beans are stored at temperatures of7 – 8^{o}C. Due to the short harvest period of French beans, proper processing and storage are essential to reduce post-harvest loses and to increase the shelf life (Zhang *et al*., 2017). Appropriate storage temperature retains the flavor and other sensory attributes important for marketing of French beans. Quality is important as many consumers consider vegetables that are firm, with good flavor and high nutritive value as having good quality (Kader, 2002). This study was carried out to evaluate the effect of harvest time and duration before cooling on the post-harvest quality and shelf-life stability of French beans.

4.3 Materials and Methods

4.3.1 Experimental design and layout

This study was conducted in Naivasha, Nakuru County Kenya. Naivasha is located Latitude0° 43′ 0″ S, and Longitude 36° 26′ 0″ E, a leading region in horticultural production for export and local market. French bean pods were harvested from a commercial planting at five different times of the day 7am, 9am, 11am, 1pm, and 3 pm. The harvested pods were later subjected to different pre-cooling durations of 0hrs, 2 hours, 4 hours, 6hour s and 8 hours. The beans were harvested in a perforated tray and later moved to a field shed made of charcoal walling and iron sheet roofing. The harvested beans were later packed into netted bags and weighed. Temperature of the beans and weight were recorded after an interval of every 2 hours interval. The ambient temperature was also recorded after every 2 hours. A split plot design was used to evaluate the effects of harvest time and pre-cooling duration on the physiochemical and nutritional quality of French beans. Harvested beans were packed into 500g modified atmospheric packaging (MAP) bags and were kept at temperatures between 4and 8 ^{0}C and later transferred to the laboratory for proximate analysis.

4.3.2 Analysis of French bean samples

4.3.2.1 Determination of French bean moisture content and weight loss

Moisture content was determined by oven drying methods according to the AOAC International (2008) Method 970.30. Samples were oven dried at 105^{o}C for 3hrs after which the samples were cooled in a desiccator for 10 minutes. Moisture content was calculated as the loss in weight expressed as a percent of the original weight of the French bean samples. The moisture loss was represented as % of the original weight. Loss of weight was determined by weighing samples every two hours. Initial weight of the sample was noted immediately after harvest and packing into the netted bag, and again after every two hours as long as the sample was still in the field shed awaiting delivery to the cold room. The samples were weighed after every two hours using digital weighing scale (Sartorius, Ag Germany). Physiological Loss in Weight (PLW) was determined using standard procedure as mentioned in AOAC (2008).

$$\text{PLW (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

4.3.2.2 The proximate analysis of French bean samples

The dry matter content in French beans was determined according to ISO 6496, 2008. Samples were dried for half one hour at 103±3°C temperature, then cooled to room temperature in a desiccator. About 5 g sample was placed in a container and put in the drying oven at 103°C for 4.0 hours then the container lid was put on, sample was removed from oven and cooled in a desiccator to room temperature. Samples were weighed and dry matter content was calculated (ISO 6496, 2008). Energetic Value was calculated based on Atwater conversion factors, which considers 4 kcal/g for protein, 4 kcal/g for carbohydrate and 9 kcal/g for fat. Carbohydrate level was calculated by deducting water, protein, crude fiber and ashes from a 100 mg French bean sample.

4.3.2.3 Determination of crude protein (CP) and ash content in French beans

The Kjeldahl method (AOAC 2008) Method 991.20 was used to determine the content of crude protein. The weighed samples were placed in the micro-Kjeldahl digestion tubes then 10 ml of concentrated nitrogen free sulphuric acid was added together with one selenium tablet as a catalyst per tube (Njoroge *et al.*, 2015). The samples were then digested in a DK20S digester (VelpScientifica, Bohemia, Italy) at 445°C for 3 hours. The products of digestion were distilled using the Kjeldahl distillation unit. The distillate was collected in a 15 ml 0.1 M HCl with a mixed indicator of methyl red plus methylene blue (Njoroge *et al*., 2015). The excess HCl was titrated against 0.1 M NaOH. Then the crude protein (CP) was calculated as; Crude protein (g/100 g) $=\frac{(V1-V2)\times(M\times1.4\times6.25)}{W}$ (Njoku *et al*., 2016) where V_2 is volume of HCl used for test portion, V_1 is volume of HCl acid used for blank test, M is molarity of acid, W is weight of test portion and 6.25 is the conversion factor. Ash content was determined according to ISO 5984:2002/Cor 1:2005, where by the samples were incinerated in a furnace at 525^{o}C for four hours until constant weight was obtained (AOAC, 2008)

4.3.2.4 Determination of crude fiber content in French beans

Crude fiber content was determined by gravimetric method according to AOAC International (2008), Method 984.04. About 5g of the samples was mixed with 25ml of 2.04 M H_2SO_4 (acid) and distilled water used to top up the contents to about 200 ml (Njoroge *et al*., 2015). The mixture was then digested using a digester model DK-20S digester from VelpScientifica, Bohemia, Italy at 445^{o}C for 30 min. A glass wool rolled at the ends of the filtering stick was inserted in the suction pump to obtain the filtrate. The second digestion was done using 1.78M NaOH with similar treatment while the final digestion washing was done in 70% ethanol and the product transferred to weighed crucibles for drying at 105^{o}C for 3 hours in an oven. Weight of the contents was recorded after the three hours and then ashing was done in a muffle furnace at 550^{o}C overnight and weights recorded. Crude fiber was then calculated as the difference between sample weights from furnace and that of oven.

Crude Fiber (g/100 g) = $\frac{\text{Residue weight from oven} - \text{weight from ashing}}{\text{original sampe weight}}$

4.3.2.5 Crude fat content in French beans

Crude fat content was determined as per AOAC 2008 guidelines. Five grams of the samples were weighted and powdered then extracted with 10 ml of hexane for a period of 24 hours. After 24 hours, the extract was filtered with filter paper and the filtrate was evaporated at a temperature of 40°C. The obtained oil was poured into amber colored 5 ml bottles and was kept on +4°C until the analysis time.

4.3.3 Statistical analysis

The parameters studied were physiological loss in weight, crude protein, fat content, carbohydrate, crude ash content, salt and moisture content. Statistical analyses were conducted using GenStat version 15 (Lawes Agricultural Trust, Rothamsted Experimental Station, UK). Analysis of variance and Tukey's multiple range tests were used to compare significant differences in time of harvesting and duration before cooling and their interaction. Means were computed and tested at 5 percent level of significance.

4.4 Results

4.4.1 Effect of harvest time and duration before cooling on moisture content, dry matter and gross energy of French bean

French beans harvested early in the morning had the highest moisture content (90%), while those that were harvested mid-morning had the least moisture content (87%) (Table 4.1). The moisture content did not significantly differ ($p \leq 0.05$) for each harvesting time and duration before cooling period. The different harvesting times resulted in different amount of moisture content with those harvested late in the afternoon having the least moisture content while those harvested in the morning had the highest moisture content (90%). The dry matter content of French bean samples harvested at different times and with different time delays before cooling significantly differed ($p \leq 0.05$). French beans harvested late in the afternoon and which were subjected to more than four hours before cooling had the highest dry matter content while those that were harvested in the morning (7 and 9am) and were subjected to more than four hours before cooling recorded the least dry matter content. Harvesting time and duration before cooling had significant effect on the gross energy of French bean samples ($p \leq 0.05$).

Table 4.1: Effects of different harvest times and duration before cooling on the physicochemical parameters of French beans

Harvesting time	Time to cooling*					
Moisture Content (%m/m)	0 hrs	2 hrs	4 hrs	6 hrs	8 hrs	Mean
7am	90.4^{ab}	90.3^{ab}	90.6^{ab}	90.2^{ab}	90.2^{ab}	90.3 ± 0.2^{a}
9am	90.4^{ab}	91.1^{ab}	96.8^{a}	90.2^{ab}	90.8^{ab}	91.9 ± 3.2^{a}
11am	87.2^{ab}	84.0^{b}	86.9^{ab}	84.1^{b}	88.9^{ab}	86.2 ± 7.2^{b}
1pm	89.5^{ab}	88.7^{ab}	88.7^{ab}	88.8^{ab}	88.3^{ab}	88.8 ± 0.4^{b}
3pm	89.9^{ab}	90.1^{ab}	89.3^{ab}	90.2^{ab}	90.3^{ab}	90.0 ± 07^{ab}
Mean	89.5	88.8	90.5	88.7	89.7	89.4
LSD (0.05)	6.4	6.4	6.4	6.4	6.4	2.8
CV (%)	4.3	4.3	4.3	4.3	4.3	4.3
Dry Matter (%m/m)						
7am	10.3^{a}	9.8^{ab}	9.4^{c}	9.9^{ab}	9.8^{b}	9.8 ± 0.4^{b}
9am	8.6^{b}	9.8^{ab}	9.0^{c}	9.1^{b}	8.9^{b}	9.1 ± 0.8^{c}
11am	9.8^{b}	9.0^{b}	10.4^{b}	9.7^{ab}	11.1^{a}	10.0 ± 0.9^{b}
1pm	10.3^{a}	11.6^{a}	10.6^{b}	10.6^{a}	11.7^{a}	11.0 ± 0.6^{a}
3pm	10.7^{a}	10.3^{a}	12.2^{a}	10.5^{a}	11.3^{a}	11.0 ± 1.0^{a}
Mean	10.0	10.1	10.3	10.0	10.6	10.2
LSD (0.05)	1.03	1.03	1.03	1.03	1.03	0.23
CV (%)	6.2	6.2	6.2	6.2	6.2	6.2
Gross Energy(Kcal/100g)						
7am	29.3^{b}	28.7^{bc}	35.3^{b}	32.3^{b}	40.3^{a}	33.2 ± 4.1^{b}
9am	37.0^{a}	42.4^{a}	42.3^{a}	41.4^{a}	42.9^{a}	41.2 ± 2.1^{a}
11am	38.7^{a}	39.0^{a}	43.3^{a}	39.0^{a}	40.0^{a}	40.0 ± 5.9^{a}
1pm	37.0^{a}	33.0^{b}	34.3^{b}	38.3^{a}	36.0^{b}	35.7 ± 2.3^{b}
3pm	34.7^{a}	37.0^{ab}	33.0^{b}	33.7^{b}	32.3^{b}	34.1 ± 2.2^{b}
Mean	35.3	36.0	37.6	36.9	38.3	36.8
LSD (0.05)	4.9	4.9	4.9	4.9	4.9	2.2
CV (%)	8.2	8.2	8.2	8.2	8.2	8.2

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

4.4.2 Effect of harvest time and duration before cooling on nutritional quality of French bean

The results related to changes in protein content, fat content and total carbohydrate depending on the time of harvesting and duration before cooling are presented in Table 3. The protein content ranged from 2.2g/100g and 2.6g/100g, which was above the normal market expectation of 2.1g/100g.(*Source- Tesco Green Bean Specification*) Beans harvested later early in the morning and later afternoon had significantly higher average protein content ($p \leq 0.05$) compared to those harvested at 11am. The protein content of various samples harvested at different times and cooled after various times did not significantly differ ($p \leq 0.05$), except for those harvested at 11am, which had slightly lower protein content compared to the rest harvesting times. The lowest protein content of French beans was recorded for samples harvested at 9am and 11am cooled in two hours and four hours respectively (1.8g/100g) while the highest protein content was recorded for samples harvested at 9am and 1pm (2.6g/100g) Averagely for all the durations before cooling, French bean samples harvested late in the afternoon recorded higher protein content when compared with those harvested early in the morning. An increase in protein content of the sample on a wet weight basis was observed in French beans samples that were harvested in the afternoon (2.4 g/100g). The protein content of freshly harvested and cooled French beans and those kept over various durations before cooling was found to be insignificantly different ($p \geq 0.05$). The fat content of freshly harvested French beans and precooled treated beans was found to be similar, the slight variations observed between the precooling times and different harvesting times were found not to be statistically different ($p \leq 0.05$). On average, samples harvested late in the afternoon had the greatest amount of total carbohydrate (7.6 g/100g) while those harvested early in the morning had the lowest carbohydrate content (6.1g/100g). French bean samples harvested at 3pm and cooled after four hours had the highest carbohydrate content (8g/100g) while those harvested very early in the morning at 7am and not cooled immediately or sooner had the least carbohydrate content 5.9g/100g and 5.8g/100g on wet weight basis. Generally, for all the harvesting times and durations before start of cooling, fat content was found not to be significantly ($p \leq 0.05$).

Table 4. 2: Effects of different harvesting times and duration before cooling on Nutritional parameters of French beans

Harvesting time	**Time to cooling***					
Protein Content (g/100g)	0 hrs	2 hrs	4 hrs	6 hrs	8 hrs	Mean
7am	2.3[a]	2.3[ab]	2.3[a]	2.2[ab]	2.3[ab]	2.2±0.04[a]
9am	2.6[a]	1.8[ab]	2.5[a]	1.9[ab]	2.3[ab]	2.2±0.6[a]
11am	2.5[a]	1.9[ab]	1.8[ab]	2.5[a]	1.8[ab]	2.1±0.5[ab]
1pm	2.3[a]	2.4[a]	2.4[a]	2.3[a]	2.6[a]	2.4±0.1[a]
3pm	2.3[a]	2.4[a]	2.5[a]	2.4[a]	2.4[a]	2.4±0.1[a]
Mean	2.4	2.2	2.3	2.2	2.3	2.3
LSD (0.05)	0.6	0.6	0.6	0.6	0.6	0.3
CV (%)	16.8	16.8	16.8	16.8	16.8	16.8
Fat content (g/100g)						
7am	0.14[a]	0.12[a]	0.14[a]	0.12[a]	0.16[a]	0.14±0.02[a]
9am	0.14[a]	0.15[a]	0.18[a]	0.14[a]	0.14[a]	0.15±0.03[a]
11am	0.14[a]	0.14[a]	0.15[a]	0.14[a]	0.16[a]	0.15±0.02[a]
1pm	0.14[a]	0.14[a]	0.14[a]	0.14[a]	0.14[a]	0.14±0.01[a]
3pm	0.14[a]	0.16[a]	0.15[a]	0.13[a]	0.16[a]	0.15±0.02[a]
Mean	0.1	0.1	0.2	0.1	0.2	0.1
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	9.7	9.7	9.7	9.7	9.7	9.7
Total carbohydrate(g/100g)						
7am	5.9[a]	5.8[b]	6.0[a]	6.9[a]	6.0[ab]	6.1±1.2[ab]
9am	5.9[a]	6.9[ab]	5.8[a]	6.6[a]	6.7[a]	6.4±0.6[a]
11am	5.9[a]	6.2[ab]	7.0[ab]	6.8[a]	7.8[a]	6.7±0.9[a]
1pm	6.7[a]	7.8[a]	7.7[a]	7.7[a]	7.9[a]	7.6±0.5[a]
3pm	6.9[a]	7.3[ab]	8.1[a]	7.0[a]	7.4[a]	7.3±0.8[a]
Mean	6.3	6.8	6.9	7.0	7.2	6.8
LSD (0.05)	1.3	1.3	1.3	1.3	1.3	0.59
CV (%)	11.8	11.8	11.8	11.8	11.8	11.8

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($P \leq 0.05$).

4.4.3 Effect of harvest time and duration before cooling on salt, total minerals and fiber content of French bean

The effect of harvesting time and duration before cooling on salt, total minerals and fiber is presented in Table 4.3. Harvesting time and duration before cooling did not significantly affect the content of salt ($p>0.05$) in French beans, however, the results revealed significant differences ($p \leq 0.05$) in the ash and fiber content. On average, French bean samples harvested at 9am recorded higher crude ash content compared to those harvested at 11am.

Highest concentration of crude ash was found in French beans harvested at 9am but cooled after 2 hours (1.87g/100g) while the lowest concentration of crude ash was recorded in samples harvested at 11am and cooled after 4 hours and 6 hours (0.77g/100g). There were significant differences in crude fiber content ($p \leq 0.05$). The highest content of fiber was observed in samples harvested at 11am (1.20 %m/m) and cooled after 4 hours while samples harvested at 1pm and cooled after 4 hours had the lowest fiber content(0.75 %m/m) .

On average, bean samples harvested mid-morning (9am and 11am) had significantly higher crude fiber content compared to those harvested early morning (7 am) and later afternoon (1pm and 3pm)

Table 4. 3: Effects of different harvesting time and duration before cooling on Crude ash content, crude fiber content, and salt content of French beans.

Harvesting time	**Time to cooling***					Mean
Salt	0 hrs	2 hrs	4 hrs	6 hrs	8 hrs	
7am	0.07[ab]	0.07[ab]	0.06[ab]	0.07[ab]	0.07[ab]	0.07±0.01[a]
9am	0.05[b]	0.08[a]	0.06[ab]	0.07[ab]	0.06[ab]	0.06±0.02[a]
11am	0.07[ab]	0.08[a]	0.07[ab]	0.08[ab]	0.06[ab]	0.07±0.01[a]
1pm	0.05[ab]	0.05[ab]	0.05[ab]	0.08[ab]	0.06[ab]	0.06±0.01[a]
3pm	0.07[ab]	0.08[a]	0.07[ab]	0.08[ab]	0.06[ab]	0.07±0.01[a]
Mean	0.06	0.07	0.06	0.07	0.06	0.06
LSD (0.05)	0.016	0.016	0.016	0.016	0.016	0.01
CV (%)	14.5	14.5	14.5	14.5	14.5	14.5
Crude Ash Content						
7am	1.02[a]	0.99[a]	1.03[a]	1.1[a]	1.3[a]	1.09±0.1[b]
9am	1.35[a]	1.87[a]	1.41[a]	1.34[a]	1.8[a]	1.55±0.8[a]
11am	0.79[a]	1.13[a]	0.77[a]	0.77[a]	0.94[a]	0.88±0.4[c]
1pm	1.18[a]	1.17[a]	1.14[a]	1.17[a]	1.02[a]	1.14±0.1[b]
3pm	1.13[a]	1.14[a]	1.19[a]	1.13[a]	1.17[a]	1.15±0.03[b]
Mean	1.09	1.26	1.11	1.1	1.25	1.16
LSD (0.05)	0.6	0.6	0.6	0.6	0.6	0.31
CV (%)	36	36	36	36	36	36.0
Crude fibre content						
7am	0.92[a]	0.93[a]	0.85[a]	1.00[a]	0.77[a]	0.89±0.08[ab]
9am	0.92[a]	0.85[a]	0.94[a]	0.93[a]	0.94[a]	0.92±0.05[a]
11am	0.95[a]	0.89[a]	1.2[a]	1.16[a]	0.92[a]	1.02±0.30[a]
1pm	0.93[a]	0.92[a]	0.75[a]	0.94[a]	0.92[a]	0.89±0.07[ab]
3pm	0.87[a]	0.91[a]	0.89[a]	0.85[a]	0.86[a]	0.88±0.07[ab]
Mean	0.92	0.9	0.93	0.98	0.88	0.922
LSD (0.05)	0.2	0.2	0.2	0.2	0.2	0.123
CV (%)	18.2	18.2	18.2	18.2	18.2	18.2

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($P \leq 0.05$).

4.4.4 Effects of harvesting time and duration before cooling on overall weight change of French beans

There were significant effects of delayed harvesting and delayed cooling on change in weight of French beans ($p \leq 0.05$). Each delay in harvesting and start of cooling resulted in reduced weight of French beans (Table 4.4). French bean samples cooled immediately after harvesting experienced the least weight loss (0.51%) while French bean samples cooled after eight hours resulted in highest weight loss (3%) There were significant differences in change in weight due to harvesting time and duration before cooling ($p \leq 0.05$).

Table 4. 4: Effects of harvest time and duration before cooling on the average percentage change in weight of French beans

Time Before cooling	Harvesting time*					Change in weight (%)
	7am	9am	11am	1pm	3pm	
0 hrs	994.8^{a}	995.0^{a}	997.9^{a}	993.1^{a}	993.7^{a}	0.51^{c}
2 hrs	984.6^{ab}	986.3^{ab}	972.9^{b}	982.9^{a}	992.6^{a}	1.6^{bc}
4 hrs	966.9^{b}	983.0^{ab}	971.8^{b}	984.9^{a}	984.2^{a}	1.9^{ab}
6 hrs	945.9^{c}	972.3^{b}	964.3^{b}	978.6^{b}	989.7^{a}	2.2^{ab}
8 hrs	968.7^{b}	973.0^{b}	982.6^{a}	990.2^{a}	988.2^{a}	2.9^{a}
Mean	972.2	981.9	977.9	985.9	989.7	1.9
LSD (0.05)	19.8	19.8	19.8	19.8	19.8	1.9
CV (%)	2.2	2.2	2.2	2.2	2.2	115.0

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

4.4.5 Effect of harvesting time and duration before cooling on product and ambient temperature of French beans

The effect of harvest time and duration before cooling on the product temperature and its relation to ambient temperature is presented in table 4.5. There was significant difference on the ambient temperatures and product temperatures with change in time of harvest and duration to cooling.The highest ambient temperature for the day was recorded at 11am (30.7^{o}C). The lowest ambient temperature was recorded at 7am (17.3^{o}C). The lowest product temperature was recorded at 7am (13.7^{o}C), while the highest product temperature was recorded at 11am (27.1^{o}C). For every increase in ambient temperature, there was increase in product temperature at harvest, an indication that the lower ambient temperature is more ideal for French bean harvesting.

Table 4. 5: Mean ambient and product temperature of French beans harvested at different times.

Harvesting time	Ambient temperature (^{o}C)*	Product temperature(^{o}C)*
7am	17.3±1.5^c	13.7±1.1^c
9am	24.0±1.0^b	22.8±1.0^b
11am	30.7±1.5^a	27.1±1.4^a
1pm	29.0±1.0^a	24.7±1.5^{ab}
3pm	24.6±1.0^b	22.8±1.0^b
Mean	25.1	22.2
LSD (0.05)	2.14	1.8
CV (%)	4.5	4.2

*Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($P \leq 0.05$).

4.5 Discussion

Harvest of vegetables results in reduced firmness due to loss of water, and as a result the produce may become increasingly susceptible to mechanical injury (Sargent, *et al*., 2007). The proximate composition of the French beans was marginally affected by delay in harvest time and start of cooling. French beans cooled immediately and within the first two hours exhibited little change in terms of moisture loss, weight loss, gross energy and change in and nutritional contents. Delay of more than four hours and above resulted in an expected pattern of increased moisture loss and loss of weight since the moisture content of any fresh produce is an index of its water activity (Osum *et al*., 2013) which measures the stability and susceptibility of the produce to microbial contamination. A short delay in cooling of French beans resulted in significant decline in crude nutritional contents of French beans. Salts content of French beans was neither affected by time of harvest nor duration before cooling.

Weight loss of French beans increased considerably with increase in duration before cooling and delays in start of harvesting period. The rate of weight loss was, however, more significant in long duration before cooling and late harvesting. According to Yagiz *et al*, (2010) green beans are considered unacceptable for sale after weight loss of more than 5%. Vegetables once harvested continue life processes, therefore within hours of harvest harvested produce can suffer irreversible losses in quality (Sargent, *et al*., 2007; Kasim and Kasim, 2015). The rate of transpiration that causes weight loss can be avoided by increasing the relative humidity, lowering the air temperature, minimizing the difference between air and product temperature and by reducing air movement (Yagiz *et al*., 2010; Rickman, *et al*., 2007). Appropriate temperature management between harvesting and marketing is effective in maintaining product quality (Arah *et al*., 2015). Keeping vegetables harvested at low temperatures of about 20^{o}C slows down the metabolic activity therefore; a delay of even one hour will lead to one day loss of shelf life (Maaben *et al*., 2006; Ismail *et al*., 2007). Respiration and metabolic process within which the crop was harvested are related to temperatures of the ambient environment (Rickman *et al*., 2007). Low temperature storage conditions can quality attributes of vegetables (Arah *et al*., 2015)

The nutritional quality of French beans was marginally affected by the harvesting time and duration before cooling. The protein content of beans cooled immediately and those cooled after some time was found to be similar however, the slight variations observed were statistically insignificant ($p \leq 0.05$). The results concur with the findings by Sobole *et al*., (2010) and Rani *et al*., (2013). The protein content of different French beans may be explained by the degradation of proteins into small peptides and amino acids due to the metabolic processes (Wu, 2016). The minor changes in protein content within the samples can be accredited to loss of water-soluble nitrogen containing compounds (Njoroge *et al*., 2015).Protein contents in raw vegetables are usually low but have high biological value. The loss of moisture results in increased protein content again addition of water during extraction may result in reduced levels of protein in vegetable samples (Osum *et al*., 2013). USDA (2005) stated an increase in protein content of vegetables after drying when compared to fresh vegetables which was due to the presence of microbes in the samples. In general, average protein content was found to be higher in samples harvested late in the afternoon, this could be attributed to results from photosynthesis process in the mid-morning hours. In as much as carbohydrate content did not significantly differ for various harvest time, there was slightly higher carbohydrate content in French beans harvested later in the afternoon. The increase in slight increase of carbohydrates in the late afternoon can be attributed to release of carbohydrates due to declining photosynthetic activity in the late afternoon. Delay in harvest and start of cooling resulted in reductions in crude fibre content.

The lowest crude fiber content was recorded for French bean samples harvested in the morning while samples harvested late in the afternoon had the highest crude fiber content. The difference in crude fiber content may be due to soil nutrient status and the age at which the beans were harvested (Bruinenberg *et al*., 2001).

The French bean samples harvested in the afternoon and cooled after six hours had the highest ash contents that ranged from 0.8 to 1.02g/100g. Fiber from vegetables serves the function of lowering blood cholesterol, weight control (Carvhallo *et al*., 2007). Fat and salt contents in these samples were not affected by the harvest time and duration to cooling. There were no remarkable differences in crude fat content in French bean. This can be attributed to the fact that fats are rich in unsaturated fatty acids which is susceptible to oxidation (Liu *et al*., 2011). According to Zang*et* *al*., (2016) immediate cold storage can reduce loss of fats in comparison to delay in start of cooling. No notable changes were realized in ash values with regards to time of harvesting and duration before cooling. This shows that ash content was not affected by time of harvesting and duration before cooling. Delay in harvesting with increase in time interval from harvesting to cooling resulted in loss of weight of various French bean samples. The reduction in weight with each delay in harvesting was due to longer increased temperature that enhanced moisture loss. Each delay in harvesting (Vincent *et al*., 2018)

On average, protein content was in line with the overall market expectation, at 2.3g/100g against market expectation of 2.10g/100g. Carbohydrate content was equally very high at 6.8/100g against retail market expectation at 3.10g/100g. Crude fibre content was however very much below market expectation, at 0.922g/100g against market expectation of 3.4g/100g. Fat content was equally lower than market expectation at 0.1g/100g against market expectation of 0.4g/100g.

4.6 Conclusion

Harvesting time and duration before start of cooling have a significant effect on the shelf life and overall quality of French beans. In general, the longer the duration to cooling and late harvesting time, the faster the deterioration of the French bean pods. French beans harvested in the afternoon have higher weight loss, but with increased protein, carbohydrate and ash content. Quality and improved shelf life of French beans starts immediately after harvesting. It is therefore important for farmers to harvest French beans early in the morning and cool them as soon as possible for improved quality.

CHAPTER FIVE:

EFFECT OF HARVESTING TIME AND DURATION BEFORE COOLING ON THE MICROBIAL QUALITY AND SHELF LIFE OF FRENCH BEAN (*Phaseolus vulgaris* L.)

5.1 Abstract

Food safety is one of the most important factors that influence success of fresh produce export. Microbial contamination is one of the food safety concerns in fresh produce industry. This study focused on understanding the correlation between harvesting time and duration before cooling on the microbial quality of French beans. French beans were harvested at different times of the day 7am, 9am, 11am, 1pm and 3pm which then held in the shed before start of cooling for 0 hr, 2 hrs, 4 hrs, 6 hrs and 8 hrs. The samples were later graded and packed in modified atmosphere packaging (MAP) bags. The samples were analyzed to determine the microbial qualities of French bean samples. Total viable counts (TVC) in these samples showed mean values ranging from 0.7 to 3.3×10^5 CFUs g-1 for total *Enterobacteriacea*, *Listeria monocytogenes*, moulds and *Staphylococcus aureus*. Of the microorganisms isolated, *Enterobacteriacea* (71.6%) was the highest, followed by *Staphylococcus aureus* (20.9%), Moulds (7.2%) and *Listeria monocytogenes* at 0.3%. The harvesting time and duration before cooling had significant effect on population of microorganisms with those harvested early in the morning having the highest population. The high presence of microbial load in samples harvested early morning is due to poor personal hygiene of the farmers harvesting and excessive leaf wetness in the morning. There is need to do further research on the effect of solar radiation on the growth and survival of *Listeria monocytogenes*, it was evident that the *Listeria* population decreased significantly with every delay in harvesting, which could also be attributed to dry leaf and pod surfaces..

Key Words: *Enterobacteriaceae*, Harvesting time, *Listeria monocytogenes*, *Phaseolus vulgaris* L., *Staphylococcus aureus*,

5.2 Introduction

French bean (*Phaseolus vulgaris* L.) is cultivated in many parts of the world for its beans which can be harvested and consumed when immature or when shelled and dried. Green beans are generally harvested at physiologically immature stage and at this time the growth is rapid, and beans exhibit comparatively high respiration rate even at low temperature (Kasim and Kasim, 2014). With conducive conditions, a number of important microbes may contaminate fresh produce thus causing faster deterioration. Physical and physiological changes in viability and quality of the fresh produce are as a result of the wounds associated with production and processing. Potential sources of contamination can be at the pre-harvest stage, and these include soil, irrigation water, manure, and even domestic animals (Likotrafiti *et al*., 2013; Buyukunal *et al*., 2015)

Fresh vegetables are heavily infested with various types of microorganisms from the soil that are problematic since they are raised in soil thus are subjected to greater risks of contamination (Luo *et al*., 2010). The internal watery plump tissues are nutrient rich and have neutral pH enhancing the possibilities of microorganisms' exploit of the host by degrading the polymers to release water and other intracellular constituents for use as nutrients for their growth. Fungi produce extracellular pectinases and hemicelluloses that are important fungal spoilage (Miedes and Lorences, 2004). The fungi are able to colonize healthy, undamaged plant tissues by gaining entry either through the calyx (flower end) during flower development, along the stem, or through natural openings. However, spoilage microorganisms can be introduced to the crop through the seed, during crop growth in the field, during harvesting and postharvest handling, or during storage and distribution.

Soilborne microbes found on produce are also present at harvesting on handling equipment, in the storage facilities, and on food contact surfaces throughout the distribution chain. Therefore, early intervention measures during plant growth and at harvesting provide drastic reductions in yield loss due to microorganisms' spoilage. Cold storage is an excellent way to preserve fresh vegetables to retain valuable sensory attributes and nutritive properties. However, cold storage only slows but does not stop enzymatic and microbial degradation that causes the development of off odors and flavors, color and texture changes, and nutrient loss during long-term storage. Microbiological quality of any produce is important, however, assuring that a product is of the highest microbiological quality is often difficult. Therefore, the present study was conducted to investigate the microbial quality of French beans harvested at different time during the day and subjected to different precooling durations.

5.3 Materials and Methods

5.3.1 Sample Collection

The samples of French bean used in this study were obtained from Naivasha, which is located at Latitude0° 43′ 0″ S, and Longitude 36° 26′ 0″ E, a leading region in horticultural production for export and local markets in Kenya. French bean pods were harvested from a commercial planting at five different times during the day 7am, 9am, 11am, 1pm, and 3 pm. The harvested pods were later subjected to different pre-cooling durations of 0hrs, 2hrs, 4hrs, 6hrs and 8hrs. The beans were harvested in a perforated tray and later moved to a field shed constructed from iron sheet roofing. The harvested beans were later packed into netted bags and weighed.

5.3.2 Determination of microbial population in French bean samples

The standard plate count technique was used to determine the microbial population in the samples. The fresh French bean samples were cut into 1-2 cm pieces with a sterile scalpel and crushed then

1g of the sample was mixed with 9 ml of distilled water and shaken properly. Using a fresh pipette at each stage, a serial dilution was carried out to 10^4dilution i.e. 1ml of the solution was drawn out using a pipette and was introduced into a second test-tube containing 9ml of distilled water and this was done serially until the last tube with 10^4 dilution was attained. Sterile petri dishes were set out for the last dilution. Using sterile pipette for each 1ml of each dilution was pipetted into the petri dishes. About 15ml of Potato dextrose agar and nutrient agar was poured into each plate. The medium was allowed to solidify, then inoculated and incubated at 37ºC for 48 hours. The numbers of colonies were counted with the use of a colony counter. The colony count was calculated by multiplying the number of colonies counted by the dilution factor

5.3.3 Enumeration of Molds

Laboratory analyses of molds were performed using ISO 21527-2:2008 standard.

5.3.4 Determination of microbial pathogens

Listeria monocytogenes was analyzed using ISO 11290-1:2004 methodology, *staphyloccus aureus* using ISO 6888-1: 1999 methodology and total aerobic count using ISO 4833-2: 2013 methodology. Approximately 25g of the produce sample was aseptically mixed with 225ml of saline water for 2 minutes. Serial dilutions were made using saline water. For each dilution, two replicate plates were prepared. Pour plating was done for yeasts and moulds and total aerobic count while spread plating was done for *Listeria monocytogenes* and *Staphylococcus aureus*. The microbiological data were expressed as Log CFU g^{-1}.

5.3.4. Data analysis

Microbial counts were transformed to logarithms before computing means and population densities were reported as log cfu g^{-1}. Data from microbiological analyses was by analysis of variance using GenStat Statistical Software, version 15 and the level of significance for all tests was 0.05 by Tukey's honestly significant difference test ($p \leq 0.05$).

5.4 Results

5.4.1 Effect of harvest time and duration before cooling on the total viable count of microbes on French bean

The changes in population of total viable counts following different harvesting times and time to cooling are presented in table 5.1. Total viable counts in these samples showed mean values ranging from 0.7 to 3.3×10^5 CFU g^{-1} for total *Enterobacteriaceae*, *Listeria*, molds, *Staphylococcus*. Significant differences were observed ($p \leq 0.05$) in microbial counts from French bean harvested at different times and stored for various times before cooling (Table 4.1). French samples harvested early in the morning had the highest total viable counts ($CFUg^{-1}$) .In general, French bean samples harvested at 7am had the highest population of total viable of all the microorganisms while those harvested at 1pm had the lowest total viable counts when compared with other harvesting times.

Table 5. 1: Total plate count (10^5) of French bean samples harvested at different times.

Harvesting time	**Time to cooling**					
	0 hrs	2 hrs	4 hrs	6 hrs	8 hrs	**Mean**
7am	4.8^a	0.1^c	2.3^a	5.5^a	4.1^a	3.3 ± 1.0^a
9am	2.7^b	0.3^{bc}	0.2^c	3.0^b	0.4^c	1.3 ± 1.0^c
11am	4.9^a	4.0^a	0.1^c	3.0^b	0.3^c	2.4 ± 1.0^a
1pm	0.0^d	0.5^b	0.9^b	1.9^c	0.1^c	0.7 ± 1.0^c
3pm	1.9^c	0.1^c	1.1^b	0.9^d	3.2^b	1.4 ± 1.0^c
Mean	2.8	1.0	0.9	2.9	1.6	1.8
LSD ($p \leq 0.05$)	0.3	0.3	0.3	0.3	0.3	1.3
CV (%)	11.0	11.0	11.0	11.0	11.0	11.0

Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

5.4.2 Effect of harvesting time and duration before cooling on population of *Enterobacteriaceae* and *Staphylococcus aureus* on French bean

Different harvesting time had significant ($p \leq 0.05$) effect on the CFUs of *Enterobacteriaceae* and *Staphylococcus aureus* isolated from Fresh bean samples (Table 5.2). Samples harvested early in the morning had the highest population of both *Enterobacteriaceae* and *Staphylococcus aureus.* French bean samples harvested at 9.00 am and 1.00 pm had the lowest population of *Enterobacteriacea* and *Staphylococcus*, however, the population increased after the second, fourth and sixth hour of holding before cooling but then reduced after the eighth hour of holding before cooling. In general, for *Staphylococcus* the population was highest following 7am harvesting followed by those samples harvested late in the evening. For *Enterobacteriaceae,* the population was highest following 7am harvesting followed by those samples harvested at 1.00 pm.

The changes in population of *Listeria monocytogenes* counts following different harvesting times and duration before cooling are presented in the Table 5.2. *Listeria monocytogenes* counts in these samples showed mean values ranging from 68 to 453 CFUs g^{-1}. Significant differences were observed ($p \leq 0.05$) in the population of *Listeria monocytogenes* from French bean harvested at different times and stored for various times (Table 5.2). French bean samples harvested early in the morning had the highest density of *Listeria monocytogenes* counts (CFU g^{-1}). However, the population continued to rise during the holding period before cooling up to 970 CFU g^{-1}. At the same time samples harvested late morning (11am) had the lowest CFUg^{-1} for *Listeria monocytogenes*. In general, samples harvested early in the morning had the highest microbial population compared with other harvesting times.

Table 5. 2: Effect of harvesting time and duration before cooling on the population (10^4) of different bacterial spp isolated from French beans

Harvesting time	Time to cooling					
Staphylococcus	0 hrs	2 hrs	4 hrs	6 hrs	8 hrs	Mean
7am	2.9^{a}	0.35^{b}	1.76^{b}	0.67^{c}	2.06^{a}	1.56^{a}
9am	0.3^{d}	0.15^{b}	0.29^{c}	1.22^{b}	0.25^{b}	0.44^{d}
11am	2.6^{b}	1.75^{a}	0.17^{c}	0.90^{c}	0.31^{b}	1.15^{b}
1pm	0.1^{d}	0.17^{b}	1.51^{b}	2.32^{a}	0.15^{b}	0.85^{c}
3pm	0.7^{c}	0.22^{b}	2.96^{a}	0.65^{c}	1.85^{a}	1.28^{a}
Mean	1.3	0.53	1.34	1.15	0.93	1.06
LSD ($p \leq 0.05$)	0.28	0.28	0.28	0.28	0.28	0.28
CV (%)	16.2	16.2	16.2	16.2	16.2	16.2
Enterobacteriaceae						
7am	1.23^{b}	0.04^{b}	2.91^{b}	0.71^{c}	2.08^{b}	3.61^{b}
9am	0.68^{c}	0.040^{b}	0.40^{c}	0.39^{cd}	0.05^{c}	0.31^{b}
11am	1.96^{a}	0.11^{a}	0.14^{c}	5.96^{b}	0.03^{c}	1.64^{c}
1pm	0.02^{d}	0.13^{a}	5.15^{a}	11.25^{a}	0.04^{c}	3.31^{b}
3pm	1.18^{b}	0.03^{b}	0.24^{c}	0.14^{d}	4.45^{a}	9.23^{a}
Mean	3.23	0.07	1.77	3.69	9.35	3.62
LSD ($p \leq 0.05$)	0.32	0.32	0.32	0.32	0.32	0.32
CV (%)	5.4	5.4	5.4	5.4	5.4	5.4
Listeria						
7am	0.02^{a}	0.02^{a}	0.039^{a}	0.050^{a}	0.097^{a}	0.045^{a}
9am	0.00^{d}	0.01^{c}	0.007^{c}	0.021^{b}	0.002^{d}	0.009^{c}
11am	0.01^{c}	0.00^{e}	0.007^{c}	0.013^{c}	0.005^{c}	0.007^{d}
1pm	0.00^{d}	0.01^{c}	0.008^{b}	0.011^{c}	0.002^{d}	0.068^{d}
3pm	0.01^{b}	0.019^{b}	0.031^{b}	0.007^{d}	0.015^{b}	0.016^{b}
Mean	0.01	0.013	0.018	0.021	0.024	0.017
LSD ($p \leq 0.05$)	0.005	0.005	0.005	0.005	0.005	0.005
CV (%)	2.0	2.0	2.0	2.0	2.0	2.0

Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

5.4.3 Effect of harvesting time and duration before cooling on population of molds on French bean

Harvesting time did not significantly affect the population of molds on the French bean samples ($p \leq 0.05$) (Table 5.3). French bean samples harvested at 11am in the morning had the least population of molds compared with other treatments but this wasn't any significantly different. In general, 6 hours delay before start of cooling resulted in the highest molds population, whereas immediate cooling realized the lowest mold population.

Table 5. 3: Effect of harvesting time and duration before cooling on the population (10^3) of molds isolated from French beans

Harvesting time	**Time to cooling**					**Mean**
	0 hrs	2 hrs	4 hrs	6 hrs	8 hrs	
7am	3.45^{a}	1.85^{b}	2.95^{b}	3.35^{c}	5.65^{a}	3.45^{b}
9am	1.66^{a}	4.18^{a}	5.38^{a}	13.58^{a}	3.40^{b}	5.64^{a}
11am	3.15^{a}	2.63^{ab}	2.67^{b}	3.77^{c}	2.66^{b}	2.98^{b}
1pm	1.55^{a}	4.35^{a}	2.05^{b}	1.55^{d}	2.60^{b}	2.42^{b}
3pm	3.95^{a}	3.52^{a}	1.75^{b}	6.45^{b}	3.28^{b}	3.79^{b}
Mean	2.75	3.31	2.96	5.74	3.52	3.65
LSD ($p \leq 0.05$)	2.01	2.01	2.01	2.01	2.01	2.01
CV (%)	33.5	33.5	33.5	33.5	33.5	33.5

Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

5.4.4 Effect of harvesting time on population of molds, *Enterobacteriaceae*, *Staphylococcus aureus* and *Listeria monocytogenes* on French bean

Different harvesting times had significant ($p \leq 0.05$) effect on the CFUs of various microorganisms isolated from French bean samples (Table 5.4). On average, the highest population of microorganisms isolated from French bean samples was for *Enterobacteriaceae* followed by *Staphylococcus aureus*. The least population of microorganism isolated from the French bean samples was *Listeria monocytogenes.* There was significant variation with regards to harvesting time except for *Enterobacteriaceae*. The amount of *Enterobacteriaceae* was highest in samples harvested at 3pm. The amount of *Staphylococcus aureus* and *Listeria monocytogenes* was highest in samples harvested at 7am. The population of all the microorganisms was generally high in the samples harvested early in the morning. There was a general reduction in microorganism population in samples harvested between 9am and 11am, however, there was a spike in the microorganism population for samples harvested at 3pm.

Table 5. 4: Effect of harvesting time and duration before cooling on the population (10^4) of different microorganisms isolated from French beans

	Time of Harvesting					
Microorganisms	**7am**	**9am**	**11am**	**1pm**	**3pm**	**Mean**
Enterobacteriacea	3.61^{a}	0.31^{a}	1.64^{a}	3.32^{a}	9.23^{a}	3.62^{a}
Staphylococcus aureus	1.55^{ab}	0.44^{a}	1.15^{ab}	0.85^{ab}	1.28^{ab}	1.05^{b}
Moulds	0.34^{b}	0.56^{a}	0.29^{b}	0.24^{b}	0.37^{b}	0.36^{b}
Listeria monocytogenes	0.04^{b}	0.09^{b}	0.01^{b}	0.01^{b}	0.02^{b}	0.02^{b}
Mean	1.39	0.33	0.77	1.10	2.72	1.26
LSD ($p \leq 0.05$)	2.57	0.38	1.20	2.41	6.95	259

Means within column followed by different letters are significantly different based on Fishers Protected LSD test ($p \leq 0.05$).

5.5 Discussion

The results show that harvesting time and time before cooling (precooling duration) had significant effect on the population of microorganisms isolated form French bean samples. Total viable counts in these samples showed mean values ranging from 0.7 to 3.3×10^{5} CFUs g^{-1} for total *Enterobacteriaceae*, *Listeria monocytogenes*, *Staphylococcus aureus* and molds. It's been reported that the bacterial population varies depending on seasonal and climatic condition and may range from 10^{4} to 10^{8} per gram. The microorganisms isolated from the French bean samples directly reflects the sanitation of the processes of cultivation, harvesting, storage and processing of the produce. vegetables are widely exposed to microbial contamination through the soil, dust, water, and during harvesting (Eni, *et al*., 2010).

Staphylococcus aureus is commonly found in the environment (soil, water and air). It is known to cause food poisoning. It is also commonly found in the nose and skin of human. It is readily killed during pasteurization or cooking. The main source of contamination is from food handlers from the nose and hands. Despite *Staphylococcus aureus* colonizing a wide range of animals, people are the main reservoir of food contamination (Montville and Mathews, 2008). The high population of *Staphylococcus aureus* realized in samples harvested early morning may be attributed to poor personal hygiene of food handlers. Even though hand wash water is normally provided, it is likely that majority of the harvesters do not wash their hands in the morning, perhaps fearing to touch cold water.

Listeria monocytogenes population was highest in samples harvested at 7am (453.4 CFU g^{-1}), decreasing steadily to lowest population in samples harvested at 1pm (68.3 CFU g^{-1}).*Listeria monocytogenes* is widespread in the environment and can spread along the chain of produce handling. At field level, *Listeria monocytogenes* is likely to be spread from contaminated irrigation water or soil arising from animal and human feces. *Listeria monocytogenes* can also be spread from contaminated equipment and surfaces during handling, e.g. contaminated creates and grading tables can be source of contamination.

Listeria monocytogenes is known to be one of the major causes of foodborne illnesses and may cause serious and sometimes fatal infections in children, frail and elderly people. It can also cause stillbirths in pregnant women. The drop in *Listeria monocytogenes* population from morning towards mid-day and afternoon can be attributed to the effect of solar radiation. There is need for more research on the impact of solar radiation on *Listeria monocytogenes* growth and survival.

The high density of bacterial pathogens isolated from the presents study are comparable to those described by Uzeh *et al*., (2009) where bacterial population as high as 9.9×10^6 was reported. Within the stores, bacterial contaminants contaminate the produce, and multiply when the environmental conditions are favorable (Abadias *et al*., 2008). The population of microorganisms isolated was in the order *Enterobacteriaceae, Staphylococcus aureus,* molds, and *Listeria monocytogenes.* These microbes have been reported in vegetables and fruits (Qadri *et al*., 2015). Harvesting time and storage temperature are important factors influencing the quality of fresh produce (Kader, 2002; Luo *et al*., 2010). However, our results show that total viable counts of microbes contaminating French beans were exceptionally high in samples harvested early in the morning but reduced when the samples were harvested as from 9am. Early morning comes with a lot of dew and leaf wetness, and these factors are predisposing for spread and multiplication of microorganisms. In addition, food handlers' personal hygiene is likely to be at its lowest early in the morning, coming from home and exchanging handshakes greetings may be a contributing factor to high levels of microbial load.

Fresh produce remains metabolically active through to harvest and during this period, physiological changes occur (Barth *et al*., 2009). Infection of fresh produce occur at any time during the crop development stage, for French beans, losses due to post harvest spoilage may be as a result of latent infection in the field by pathogens that become active following infection during harvest, cleaning, storage, and distribution (Barth *et al*., 2009). Presence of the pathogen, in a conducive environment during storage enhances density of these pathogens and therefore spoilage.

The results in the present study show that the population of *Listeria monocytogenes* was least compared with other isolated microbes. Given widespread use of animal fecal wastes in agriculture, the availability even in small quantities is of great concern since *Listeria mononcytogenes* is an important foodborne pathogen causing severe illness with high mortality rate (Directorate, 2002). The occurrence of *Listeria monocytogenes* in vegetables has been reported by various researchers with different rates of prevalence (Arumugaswamy *et al*., 1994; Breer and Baumgartner, 1992; De Simon *et al*., 1992)

In the present study, mold counts isolated ranged from 2421 to 5645 CFU /g. Molds were also detected by researchers Avecedo *et al*., in levels of 4.5×10^4 CFU/g in salad samples, and by Badosa *et al*., in levels of 7×10^4. The authors reported the presence of *Penicillium*, *Aspergillus*, and *Fusarium* spp. in salads. Many of the molds belong to genera that are toxigenic, this indicates potential for mycotoxins production on vegetables (Jeddi *et al*., 2014). The high populations of these microorganisms indicate a possibility of unhygienic production environments and improper handling and processing of the produce (Onuora *et al*., 2013). The colonization of the produce with these microorganisms shows their ability to establish within the produce to initiate decay.

During harvesting, and throughout the handling before storage, it is important to minimize the wounds and bruising to reduce the entry points for these pathogens. Fungi primarily enter fresh vegetables through the formation of germ tube that penetrates the cuticle and epidermis (Barth *et al*., 2009). However, most spoilage microorganisms infect and initiate decay at wounds in the epidermal layer, and through natural openings such as stomata and lenticels. Microbial contamination of produce is one of the major concerns on Food Safety, especially when the product involved is a ready to eat.

Management of microbial contamination with regards to food safety management calls for robust systems based on HACCP principles, working to identify all the risks and have in place measures to reduce these risks in the supply chain. French bean contamination in the field may come from various sources, including irrigation water, especially when the method of irrigation used delivers water directly onto edible part of the crop. Low-lying crops are known to be more susceptible to bacterial contamination due to ease of splashes from the soil. Where animal manure is used, there is greater risk of bacterial contamination. According to Global G.A.P., it is advisable to use organic and animal manure several days before harvest to reduce risk of contamination.

Considering the food safety risks associated with microbial contamination, it is important for farmers to have in place robust food safety management systems that shall prevent or reduce contamination. This includes and not limited to Good Agricultural Practice (G.A.P), Hazard Analysis Critical Control Points (HACCP), food safety and hygiene trainings, microbial testing and validation and equipment hygiene. Considering the public health issue, fresh vegetables are common sources of various pathogenic microorganisms. It is important that farmers use good agricultural practices and good manufacturing practices while farming. French bean farmers should be informed on the microbial sources of contamination and therefore should be trained on hygienic production of this produce.

5.6 Conclusion

Time of harvesting has an effect on the microbial contamination of French beans. There tends to be higher microbial contamination for French beans harvested early in the morning than those harvested later in the day.

CHAPTER SIX:

PERFORMANCE OF SOLAR POWERED PROTOTYPE VAPOUR COMPRESSION COOLING SYSTEM IN FRENCH BEANS STORAGE

6.1 Abstract

The quality and shelf life of vegetables may be affected within hours of harvesting lest the produce is cooled immediately. Longer storage periods make a solar powered evaporative cooling system suitable for use in rural areas that are not connected to the grid. This study aimed at developing an effective and affordable solar powered cooling system to improve the quality of French beans in small-holder farms in Kenya. Conventional field sheds are mostly covered with iron sheets, and where possible walls are often made of charcoal. The prototype was made following existing mathematical modeling equations developed for solar cooling of meat and milk products. Solar power was used to run cooling system during the day with excess energy being used to freeze water into ice. Temperature sensor was fitted centrally to record temperature fluctuations. Freshly harvested French beans were stored under conventional field shed and solar-powered prototype cooler. Weight and temperature of the stored produce was monitored an hourly interval. At the end of the day, the stored produce was processed normally and packed into modified atmosphere packaging (MAP) bags and stored for a period of 7 days in a cold room. At the end of the seventh day, levels of oxygen and carbon dioxide were measured using Bridge gas analyzer. There were significant differences ($P \leq 0.05$) in weight loss between produce stored in the conventional shed and produce stored in the fabricated solar cooler prototype. The weight of the stored produce reduced by 5% and 2.8% after seven hours under conventional field shed and fabricated solar cooler respectively. Volume of carbon dioxide and oxygen released from produce stored in conventional shed and those stored in fabricated solar cooler prototype significantly ($P \leq 0.05$) differed. Higher volume of CO_2 accumulation was realized in produce stored in the conventional cooling method than those stored in the fabricated solar-powered cooler. The solar-powered cooler maintained and reduced temperature and maintained the balance between carbon dioxide and oxygen thus reduced the metabolic activities thereby enhanced the shelf life and quality of the produce

Key words: Charcoal Cooling method**,** French beans, temperature**,** Solar cooler, weight loss,

6.2 Introduction

French bean (*Phaseolus vulgaris* L.) requires gentle and tender handling after harvest to maintain high quality until the produce gets to the consumer. Speed and efficiency of operations are critical during production, transportation, and storage (Okello *et al.*, 2007). French beans usually hold massive numbers of spoilage microbes during harvest mainly due to contact of the produce with the soil during growth. Other important sources of contamination are from the air and from handlers. Spoilage of the beans is dependent upon high temperature that increases the rates of metabolism (Abadias *et al*., 2008).

Losses after harvest are due to lack of storage facilities (Taye and Olorunisola, 2011). In developing countries losses as high as 30-40% due to defects in handling, transportation, storage and marketing have been reported (Atanda *et al*., 2011). Storage losses are mainly due to respiration, evaporation, storage diseases and changes in the chemical composition of the produce (Basediya *et al*., 2013). However, the losses can be reduced by maintaining suitable conditions within the store. This requires an efficient cold storage system in order to control temperature at all points of the supply chain. This ensures that the produce reaches consumers in prime condition to guarantee best prices to the retailer and producer. Majority of the large farmers with the means are able to follow up on the strict standards, however, small scale and medium sized farmers face myriad of challenges associated with the implementation of the standards. Proper temperature and relative humidity control are the key to prolonging the storage life and marketable quality of French beans (Basediya *et al*., 2013). Conventional storage systems are not only inappropriate but are also becoming unsustainable due to heavy reliance on charcoal and grass which have great impacts on environmental degradation. (Olosunde *et al*., 2015). Evidence has been provided that solar powered cooling methods can achieve favorable temperatures for storage of vegetables, offering practical solutions to farmers in rural areas. Running cost is reduced with solar power source and this is relevant in a tropical environment where adequate amount of solar energy is received through the season. Therefore, it is essential to devise a storage system that is solar powered to ensure an average farmer can afford to store produce with minimum energy input.

Cold chain-controlled system is very critical in the management of quality of French beans. Freshly harvested French beans have to be cooled immediately to reduce deterioration of quality and loss of weight. French beans require storage temperature ranging from 5-15 ºC. Any storage below 5 ºC is not ideal, this may cause chilling injury. Immediate cooling after harvest is critical, mainly to eradicate field heat. Harvested produce also continue to respire after harvesting, any delay in cooling the produce will enhance respiration rate and eventually degradation.

Under conventional field conditions with no refrigerated coolers, storage is normally done in field sheds with no temperature control. French beans continue to respire and transpire even after harvest, and it is for this reason that the duration before start of cooling needs to be as short as possible. The duration before start of cooling depends on a number of factors, but predominantly determined by the distance from harvesting field and the cooling facility. At temperatures between 5-10ºC, French beans can be stored for up to 7 days, however, they respire and transpire continuously even after harvest, and it is for this reason that the duration before start of cooling needs to be as short as possible. The duration before start of cooling depends on a number of factors, but predominantly determined by the distance from the harvesting field and the cooling facility.

6.3 Materials and Methods

6.3.1 Development of a solar powered cooler prototype

The design process of the cooler involved the use of data collected on the existing coolers, in order to overcome the gaps identified in coolers currently used by farmers. The prototype used existing mathematical modeling equations that have been developed for solar cooling of meat and milk products to check on feasibility of similar systems for French beans. An upgraded solar cooler for French beans was developed based on this data using evaporative cooling while incorporating data collected in objectives 3 and 4.

6.3.1.2 Design consideration

The fabricated solar cooler's rectangular walls were made of 100mm insulated Expanded Polystyrene (EPS) , sandwiched by 10mm Medium Density Fiber (MDF) board outer shell and 5mm confute polyethylene sheeting interior (Fig 6.1). Extra energy required to cool was estimated with the Fourier heat conduction equation and appropriate photovoltaics used to generate this energy. Photovoltaics were fitted on the roof to convert solar power to electrical energy. Solar energy was used to run cooling system in the store during the day with excess energy being used to freeze water into ice. A temperature sensor was centrally placed in the cooler to record temperature fluctuations. A fan, with power of Ef (kW) was also fitted at the corner to maintain air is circulation. The system was also equipped with sensors that were connected to the control system. Using the Spick platform, data on conditions within the cooler could be configured and transmitted through the internet and send notifications to the user

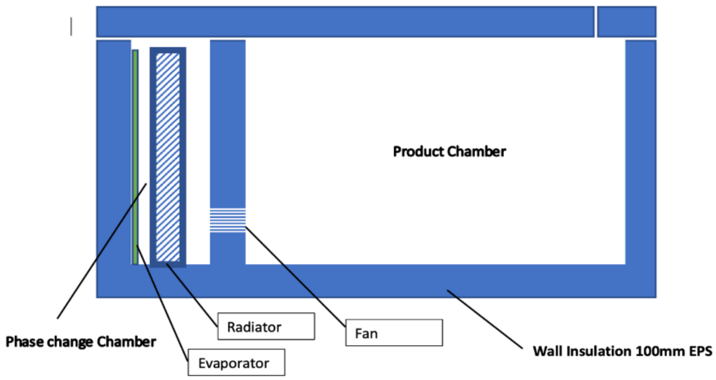

Figure 6. 1: Schematic diagram of the solar cooler

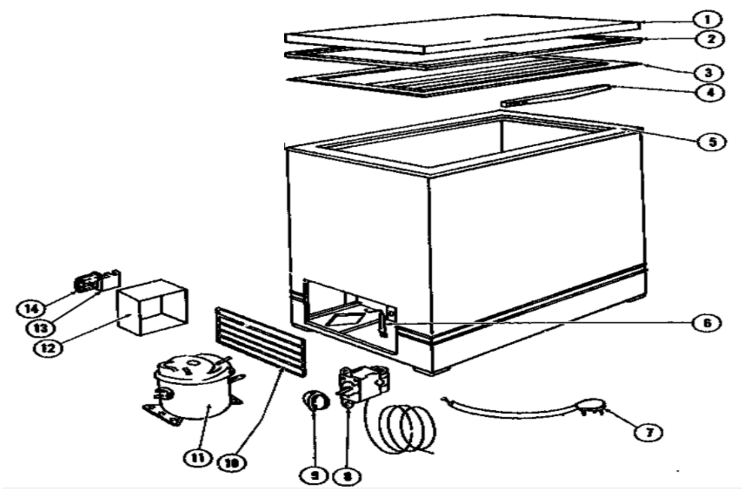

Figure 6. 2: Structural layout of the solar cooler measurements and control system

1. Lid 100mm EPS[1] insulated
2. Foam rubber air seal
3. Evaporator
4. Sensor Rack
5. Walls 100mm Expanded Polystyrene (EPS) insulated sandwiched by 10mm MDF[2] outer shell and 5mm confute polyethylene sheeting interior
6. Compressor compartment
7. 12v DC Power plug
8. External temperature sensor
9. Dial

10. Condenser

11. 24DC Compressor Danfoss BD50K

12. 12v DC condenser Fan

13. Frozen chamber Digital thermostat & compressor controller

14. Produce chamber digital thermostat and fan controller

Figure 6.3– Temperature display panel for cold chamber and produce chamber

Figure 6. 4: L-The upper portion of the solar cooler and (R)- packed French beans stored in the cooler

Figure 6. 5- Cold store with solar-powered vapor compression refrigeration system.

6.3.1.3 Refrigeration operation cycle, temperature and carbon dioxide control

The system is designed to maintain produce temperature between 6^oC to 10^oC and maintain CO2 levels below 3%. It consisted of two chambers, the cold chamber and the produce chamber.

6.3.1.4 The cold chamber

The cooling cycle comprises of the following components; compressor, condenser (heat exchanger), radiator with water/ice (phase change material in a radiator, refrigerant (R600),evaporator plate and fan. Within the two chambers two cooling processes occur, the first process begins in the cold chamber where water contained in a heat exchanger/radiator is used as the phase change material to "store negative thermal energy as ice and maintained between -1^oC and 4^oC via thermostatic control. The cold chamber control consists of digital thermostat mounted externally but with internal probe which monitors the temperatures between -1^oC and 4^oC by turning off the compressor when temperature falls below -1^oC and again turns it on when temperature goes above 4^oC to start extracting energy from the cold chamber.

In the cold chamber, there is water which is the phase change material held in a radiator. Water provides cooling even without solar power. In addition, two lead acid gel battery were installed to run the system even beyond the solar availability. The water is cooled below 0^oC by typical refrigeration cycle that employs a solar-powered DC compressor. The refrigeration cycle is a closed-loop cycle that consists of a compressor, a condenser, an evaporator plate and a refrigerant (R600) which is an organic, biodegradable and Chlorofluorocarbon (CFC) free thereby making it compliant with current International Standards. The compressor compresses the refrigerant which is liquifies at -40^oC and at pressure of 3.5 bar, thereby pushing the refrigerant through the evaporator thereby forcing it to liquify and drops the temperature to - 40^oC.

The refrigerant then absorbs thermal energy from the cold chamber to the condenser/heat exchanger which is mounted outside the chamber. The thermal energy is released to the exterior of the chamber and exhaled with the help of the fans. It is through the above process that the cols chamber gets cooled. The aim of the above process is to keep the phase change material (water) below its freezing point.

The main chamber is set to maintain the produce temperature between 6^oC and 10^oC, it achieves this through a closed-loop control system that includes a DC powered fan blowing cool air from the cold chamber into the produce chamber. The control within this loop is achieved a second digital thermostat and a digital temperature probe mounted in the produce chamber. The temperature range in the produce chamber is set at 6^oC to 10^oC. When temperature rises beyond 10^oC the thermostat switches on the fan which blows the cold air from the cold chamber to the storage chamber to maintain the temperatures within the range of 6^oC to 10^oC. This is achieved by a DC fan installed between the walls of cold and produce chamber that blows cold air from the cold chamber into the produce chamber.

Using the Baird and Gaffney (1976) equation, size, shape, thermal property of the product, the convective coefficient, and flow rate of the cooling medium was used to design the chamber. The system is equipped with sensors which collects data and sends it to the control system which in turn actuates solenoids and fans it also sends the data to things Spick platform where the data is analyzed in graphical format and can be configured to send email and short message notification to the user.

When the produce stored in the cooler respires, it emits CO_2 .The storage chamber is equipped with an air quality sensor. When the CO_2 level rises beyond 30000ppm the control system powers the solenoid which opens an air valve, a fan located next to the solenoid blows the CO_2 out of the chamber this ensures that the CO_2 levels in the chamber are maintained within the range of 400ppm-30000ppm into (0.01-0.03%) thereby reducing the rate of breakdown of the produce.

6.3.2 Conventional cooling system

The conventional cooling system was a simple structure made of iron sheets on top and on the sides, with some provisions for ventilation provided by way of use of chicken mesh wire at halfway the sides of the wall. It is the most widely used cooling system by smallholder farmers in Kenya. It some cases, charcoal may be stuck in between chicken mesh to create a wall, giving rise to the name charcoal cooler. However, due to rising pressure on environmental conservation and move towards green energy, use of charcoal has been highly restricted.

Figure 6. 6- Conventional produce shed

6.3.3 French bean harvesting

The French bean samples were harvested at different times 8am, 10am 12pm and 2pm from the farm and immediately sorted and weighed into 500g portions. Proper care was taken to avoid mechanical injury in order to reduce deterioration. French beans were packed into five 500g packs each and subjected to two different storage conditions, one portion was stored in the conventional field shed while the other was stored in the developed solar-powered cooler. The samples were labeled as per the harvesting time and storage condition, FS for field shade and SC for solar powered cooler. The harvested French beans samples were kept in the various storage conditions until 4pm. At 4pm, the harvested samples were transported to the pack house and kept in usual produce cold room awaiting processing. The following day, the 500g portions were processed into 2 packs of 200g each, packed into a modified atmosphere packaging (MAP) bag to ensure the product remained fresh for the longest possible duration. The packed products were stored in cold rooms at temperature between 4-8^{o}C. Quality parameters such as product weight and temperature were monitored and from each batch a sample was taken for gas analysis. The performance and efficiency of the field shed, and the solar cooler were evaluated.

6.3.4 Determination of physiological weight loss

The weight loss was measured using a digital weighing scale (Constant 14192-1F model, China). A number of each French bean bag were chosen and marked for the weight assessment change. The samples were weighed on the first hour of storage and then hourly until the 3pm in the afternoon. The mean weight and the mean change in the weight of the samples were determined. French bean with time during the storage period was calculated. The change in weight was expressed as percentage weight loss using the following formula;

Percentage weight loss = $\frac{W1-W2}{W1} \times 100$

Where W_1 = Initial weight of sample (g); W_2 = Weight of sample after storage (kg).

6.3.5 Determination of cooling efficiency and measurement of temperature

Cooling efficiency was determined by dividing the observed temperature decrease by the maximum potential temperature decrease. The cooling efficiency was calculated using the formula by Verploegen *et al*., 2019)

Cooling efficiency = $\frac{\text{Ambient Temperature} - \text{Interior Temperature}}{\text{Ambient Temperature} - \text{wet bulb Temperature}}$

The interior temperature was determined by the reading of the temperature sensor out at the center of the cooler. A thermometer with the bulb wrapped in wet muslin was used to measure wet bulb temperature.

6.3.6 Data analysis

The data on weight loss, product temperature and cooling efficiency was subjected to analysis of variance using GenStat statistical package version 15 and the least significant difference was used for separation of treatment means at 5% significance level. The weight loss in relation to cooling time was also observed

6.4 Results

6.4.1 Comparison between physiological weight of French beans stored in solar cooler and conventional cooler depending on the harvesting time

The results of the physiological weight loss for the produce stored under both conventional conditions and the solar powered cooler for the produce harvested at 8am and immediately put in the coolers in the morning is presented in Table 6.1. There were significant differences ($P \leq 0.05$) between the storage method and the storage duration. There was higher weight loss in conventional storage method compared with the solar-powered cooler and it changed from 500 g to 475 g after seven hours of storage. In the solar powered cooler, there was small reduction in physiological weight from the initial 500g to 486.8g after seven hours of storage.

Figure 6.7 shows weight loss in French beans. Weight loss in French beans stored in conventional method was observed to be 5% of the original weight at harvesting after seven hours of storage while only 2.6% of the original weight was lost after seven hours of storage for

Table 6.1: Physiological weight of French beans harvested and stored at 8.00am in conventional and solar powered prototype cooling

Time of day	Cooling Method			
	Charcoal cooler (g)	**Percent change in weight**	**Solar-powered Cooling method(g)**	**Percent change in weight**
8am	500.0^{a}	0.0^{i}	500.0^{a}	0.0^{i}
9am	497.6^{a}	0.4^{h}	497.8^{a}	0.44^{hi}
10am	495.5^{b}	0.9^{gh}	497.2^{a}	0.56^{h}
11am	487.0^{c}	2.6^{de}	496.2^{b}	0.7^{gh}
12pm	484.1^{c}	3.2^{cd}	494.6^{b}	1.1^{gh}
1pm	481.1^{d}	3.7^{bc}	492.0^{b}	1.6^{fg}
2pm	478.4^{e}	4.3^{ab}	489.0^{c}	2.2^{ef}
3pm	475.0^{e}	4.9^{a}	486.8^{c}	2.6^{de}
Mean	487.4	2.5	494.2	1.2
LSD ($P \leq 0.05$)	2.14	0.49	2.14	0.49
CV (%)	0.3	21.5	0.3	21.5

LSD test ($P \leq 0.05$).

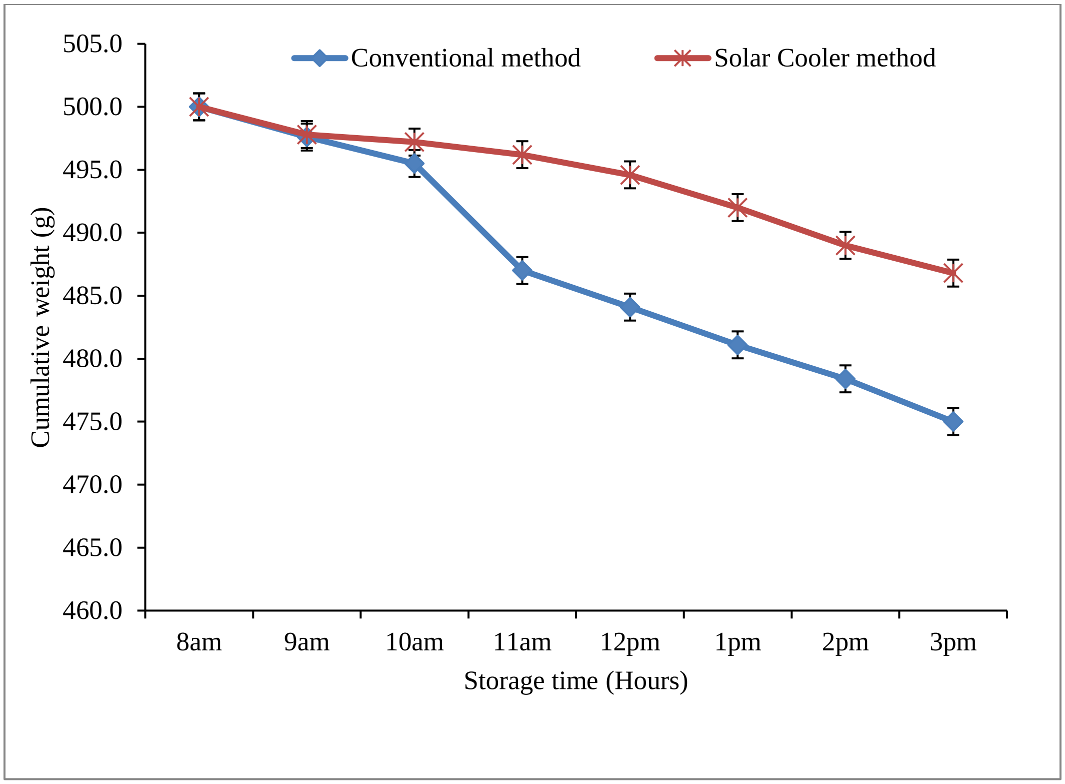

Figure 6.7: Cumulative weight loss of French beans stored in conventional and solar powered cooler

The differences in physiological weight loss were significant ($P \leq 0.05$) between the storage methods and the storage times (Table 6.2). The weight loss of French beans in conventional storage method was higher compared to those that were stored in solar powered cooler and it changed from 500g to 476g after six hours of storage. In the solar powered cooler, there was small reduction in physiological weight from the initial 500g to 490g after five hours of storage.

Table 6. 2: Physiological weight of French beans harvested and stored at 10.00am in conventional and solar powered cooler

Time of day	Cooling Method			
	Charcoal cooler (g)	**Percent change in weight (%)**	**Solar Cooler method(g)**	**Percent change in weight (%)**
10.00am	500.0^{a}	0.0^{g}	500.0^{a}	0.0^{g}
11.00am	497.4^{ab}	0.5^{fg}	496.8^{ab}	0.6^{fg}
12.00pm	491.4^{cd}	1.7^{de}	495.0^{bc}	1.0^{ef}
1.00pm	485.8^{ef}	2.8^{bc}	492.0^{cd}	1.6^{de}
2.00pm	481.3^{f}	3.8^{b}	488.8^{ef}	2.2^{cd}
3.00pm	476.0^{g}	4.8^{a}	490.2^{de}	1.6^{cd}
Mean	488.7	2.27	493.8	1.24
LSD (P≤0.05)	2.8	0.56	2.8	0.56
CV (%)	0.4	25.1	0.4	25.1

LSD test (P ≤ 0.05).

The results of the physiological weight loss for the produce harvested at noon and at 2pm and stored under both conventional conditions and the solar powered cooler is presented in table 6.3. There was significant difference (P≤0.05) between the storage methods and the storage duration. The weight loss of French beans in conventional storage method was high compared to those that were stored in solar powered cooler. The loss of physiological weight in conventional storage method changed from the initial 500g to 490g after three hours of storage. In the solar powered cooler, there was small reduction in physiological weight from the initial 500g to 497g after three hours of storage. As for the French beans harvested at 2pm, there was slight reduction in weight in the two storage methods. The produce stored under conventional methods reducing from the initial 500g to 496g while those in solar powered cooler reduced from 500g to 498g after 2 hours of storage

Table 6. 3: Physiological weight of French beans stored in Charcoal and solar powered cooler for produce harvest at 12 noon and 2.00pm

Time of day	Cooling Method			
	Charcoal cooler (g)	**Percent change in weight (%)**	**Solar Cooler method (g)**	**Percent change in weight (%)**
12.00pm	500.0^{a}	0.0^{e}	500.0^{a}	0.0^{e}
1.00pm	496.2^{c}	1.5^{c}	498.2^{ab}	0.4^{de}
2.00pm	487.4^{d}	2.5^{b}	497.3^{b}	0.5^{d}
3.00pm	481.4^{e}	3.7^{a}	495.8^{b}	0.8^{d}
Mean	490.1	1.9	497.8	0.4
LSD (P≤0.05)	1.5	0.32	1.5	0.32
CV (%)	0.2	20.8	0.2	20.8
Time of day	Cooling Method			
	Charcoal cooler (g)	Percent change in weight (%)	Solar Cooler method(g)	Percent change in weight (%)
2.00pm	500.0^{a}	0.0^{c}	500.0^{a}	0.0^{c}
3.00pm	496.3^{c}	0.73^{a}	498.3^{b}	0.34^{b}
Mean	498.2	0.36	499.2	0.17
LSD (P≤0.05)	0.65	0.12	0.65	0.12
CV (%)	0.1	35.0	0.1	35.0

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test (P ≤ 0.05).

6.4.2 Effects of both cooling systems on the produce temperatures

The difference in temperature of produce significantly (P ≤ 0.05) differed between the cooling methods and storage time (Table 6.4). Under conventional cooling, the temperature of produce was lower in the morning hours and increased in the afternoon while the temperature of the produce in solar powered cooling system only slightly increased which was insignificant. The produce temperature in conventional stores increased by 20% after 7 hours of storage. For the produce harvested at 10am in the morning, there was significant difference (P ≤ 0.05) between the storage condition and the storage duration (Table 6.5). In conventional cooling system, French beans stored for 4 hours recorded high temperature levels (18.2^{o}C) compared to those that had been store for fewer hours (16.4^{o}C). However, in solar powered cooling system, there was no significant difference (P ≤ 0.05) between the cooling periods for the produce.

There was significant difference between storage duration and the harvesting time for both the cooling conditions (Table 6.6). The produce harvested at 12pm and at 2pm had high temperature levels of 18.7 and 18.3 respectively, however, the temperature levels continued to decline with the number of hours of cooling. In conventional cooling system, the temperature levels declined by about 7% after 4 hours while the temperature levels for produce in solar powered cooling system reduced by about 18%.

Table 6.4: Effect of Charcoal cooling and Solar powered prototype cooling on the temperature of French beans harvested and stored at 8am

Time of day	Cooling Method	
	Charcoal cooler (°C)	Solar-powered prototype cooling(°C)
8.00am	14.2^{g}	15.6^{cde}
9.00am	14.4^{g}	15.7^{cde}
10.00am	15.1^{f}	15.6^{def}
11.00am	16.2^{c}	15.4^{ef}
12.00pm	17.4^{ab}	15.4^{ef}
1.00pm	17.6^{a}	15.8^{cde}
2.00pm	17.8^{a}	15.9^{cd}
3.00pm	16.8^{b}	15.9^{cd}
Mean	16.2	15.7
LSD ($P \leq 0.05$)	0.3	0.3
CV (%)	1.5	1.5

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test ($P \leq 0.05$).

Table 6.5: Effect of both Charcoal and Solar powered cooling systems on the temperature of French beans harvested at 10.00am

Time of day	Cooling Method	
	Charcoal cooler (°C)	Solar Cooler method(°C)
10.00am	17.2^{c}	16.2^{cd}
11.00am	16.4^{c}	16.3^{cd}
12.00pm	17.4^{ab}	16.0^{cd}
1.00pm	18.2^{a}	15.9^{d}
2.00pm	17.7^{a}	15.4^{d}
3.00pm	17.4^{ab}	16.1^{cd}
Mean	17.4	15.9
LSD ($P \leq 0.05$)	0.67	0.67
CV (%)	3.1	3.1

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test ($P \leq 0.05$).

Table6.6: Effect of Charcoal cooling and Solar powered prototype cooling on the temperature of French beans harvested and stored at 12 and at 2pm

Harvesting and storage at 12 noon	Cooling Method	
	Charcoal cooler method(°C)	Solar Cooler method(°C)
12.00pm	18.7^{a}	18.3^{a}
1.00pm	17.6^{b}	16.5^{c}
2.00pm	17.6^{b}	15.6^{d}
3.00pm	17.4^{b}	15.5^{d}
Mean	17.8	16.5
LSD (P≤0.05)	0.36	0.36
CV (%)	1.6	1.6
Harvesting and storage at 2.00pm	**Cooling Method**	
	Charcoal cooler method	Solar Cooler method
2.00pm	20.6^{a}	19.2^{b}
3.00pm	18.9^{ab}	16.4^{c}
Mean	20.2	17.8
LSD (P≤0.05)	0.63	0.63
CV (%)	2.4	2.4

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test (P ≤ 0.05).

Figure 6.8 shows the relationship between the product temperature and storage duration. The temperature for the produce stored in conventional shed increased by about 28% from 14°C to 18°C after 7 hours of storage. The produce stored in solar powered cooler had average product temperature of 15.7°C.

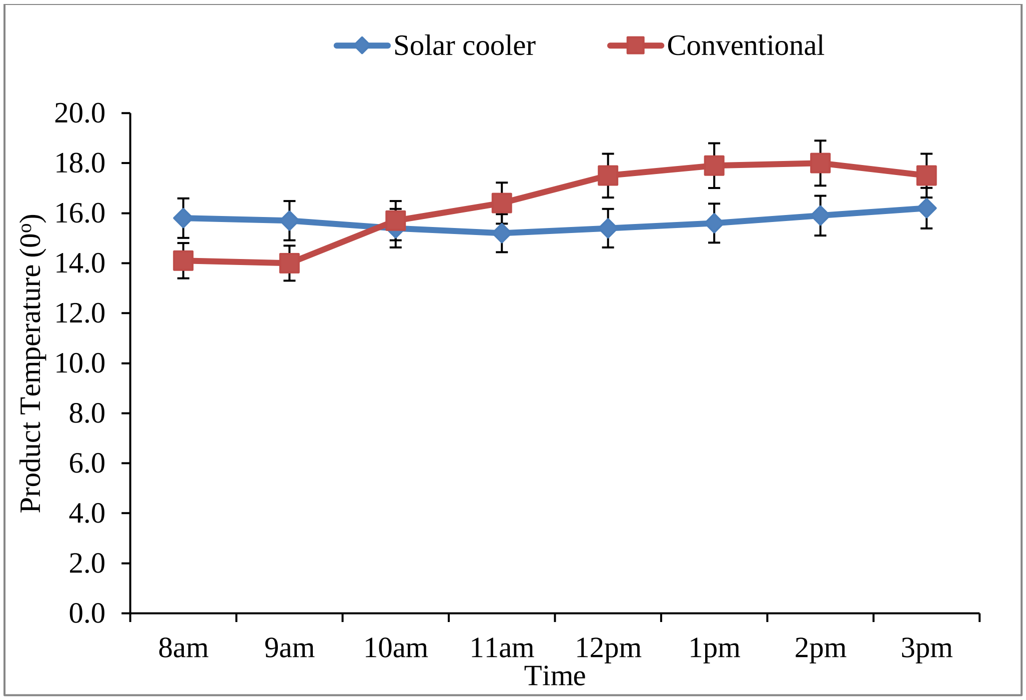

Figure 6. 8: Product temperature loss of French beans stored in conventional and solar powered coolers

6.4.3 Effect of cooling system and harvesting time on cooling efficiency

For the produce harvested at 10am in the morning, according to the results, the mean degree of cooling for produce in conventional cooling system was 0.36 while that of solar powered cooling system was 0.68 (Table 6.8). Consequently, the effectiveness and efficiency of the solar powered cooling system was 47% more than the conventional cooling method.

For the duration of the experiment, for produce harvested at noon, the mean degree of cooling was 0.4 and 0.95 for conventional and solar powered cooler respectively. Consequently, the effectiveness of the solar powered cooling system was 58% more than the conventional cooling method.

Table 6. 7: The efficiency of different method of cooling systems on produce harvested and stored at 8am

Harvesting time- 8am / Storage time	Charcoal cooler method	Solar Cooler method
8.00am	0.34^{cd}	-0.92^{e}
9.00am	0.65^{b}	0.67^{ab}
10.00am	0.26^{d}	0.50^{bc}
11.00am	0.11^{d}	0.60^{b}
12.00pm	0.25^{d}	0.50^{bc}
1.00pm	0.19^{d}	0.69^{ab}
2.00pm	0.89^{a}	0.60^{b}
3.00pm	0.14^{d}	0.57^{bc}
Mean	0.35	0.28
LSD (P≤0.05)	0.135	0.135
CV (%)	33.8	33.8

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test (P ≤ 0.05).

Table 6. 8: The efficiency of the different method of cooling systems on produce harvested at 10am

Harvesting time- 10am / Storage time	Charcoal cooler method	Solar Cooler method
10.00am	0.50^{cd}	0.85^{a}
11.00am	0.12^{e}	0.78^{ab}
12.00pm	0.25^{de}	0.58^{abc}
1.00pm	0.23^{de}	0.72^{ab}
2.00pm	0.89^{a}	0.55^{bc}
3.00pm	0.15^{e}	0.58^{cd}
Mean	0.36	0.68
LSD (P≤0.05)	0.198	0.198
CV (%)	30.0	30.0

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test (P ≤ 0.05).

Table 6. 9: The efficiency of the different method of cooling systems on produce harvested at 12pm and 2pm

Harvesting time-12 noon Storage time	Charcoal cooler method	Solar Cooler method
12.00pm	0.40^{d}	1.33^{a}
1.00pm	0.19^{e}	0.89^{b}
2.00pm	0.85^{b}	0.74^{c}
3.00pm	0.15^{e}	0.83^{b}
Mean	0.4	0.95
LSD (P≤0.05)	0.05	0.05
CV (%)	5.4	5.4
Harvesting time- 2.00pm Storage time	Charcoal cooler method	Solar Cooler method
2.00pm	0.68^{c}	1.70^{a}
3.00pm	0.66^{c}	0.97^{b}
Mean	0.68	1.34
LSD (P≤0.05)	0.14	0.14
CV (%)	10.1	10.1

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test ($P \leq 0.05$).

6.4.4 Effect of cooling systems on gaseous production

The production levels of gases from the produce in presented in table 6.10. There was a significant difference ($P \leq 0.05$) in the volume of carbon dioxide released between the two cooling systems. Sample 5A accumulated more CO_2 compared with the rest in conventional cooling system. There were significant differences ($P \leq 0.05$) in the volume of oxygen released by the produce in conventional cooling system. French samples harvested at 8am, 10am and 12 noon and stored in the conventional shed accumulated more oxygen levels compared with other samples.

Figure 6.9 shows the reduction in concentration of oxygen and an increase in concentration of carbon dioxide over a period of eight hours causing a gradient. Initially, the amount of carbon dioxide released is less but continues to increase with storage time at the same time, the amount of oxygen within the chambers reduces to low levels after eight hours storage period. Thus, inside the cooling chambers, the oxygen amount reduces while that of carbon dioxide increases.

Table 6. 10: Gaseous levels from French beans stored in Solar powered and conventional cooling systems

Sample	Charcoal cooler method (Units)		Solar Cooler method (Units)	
	Carbon dioxide	Oxygen	Carbon dioxide	Oxygen
1A	13.4[b]	9.9[a]	10.2[a]	10.4[a]
2A	12.6[b]	9.2[a]	9.5[a]	10.7[a]
3A	14.6[ab]	9.3[a]	10.6[a]	9.6[a]
4A	16.7[a]	7.2[b]	10.2[a]	10.6[a]
5A	17.3[a]	7.8[b]	10.5[a]	9.8[a]
Mean	14.9	8.7	10.2	10.2
LSD ($P \leq 0.05$)	3.3	1.3	3.3	1.3
CV (%)	18.2	8.8	18.2	8.8

Values followed by the same letter within the same row are not significantly different between the treatments using Fishers Protected LSD test ($P \leq 0.05$).

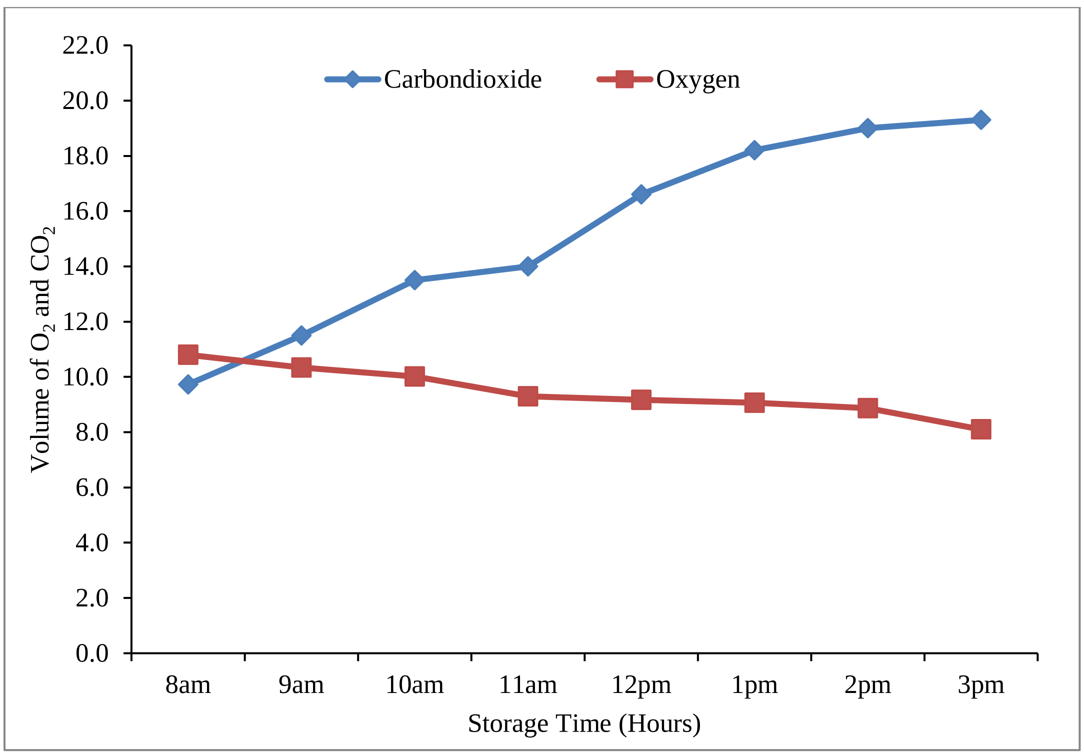

Figure 6.9: Changes in CO_2 and O_2 concentrations (ppm) with time within the conventional cooling chambers

6.5 Discussion

The study has demonstrated that fabricated solar-powered cooler was more efficient in in maintaining quality and freshness of French beans than the conventional field shed. Produce stored in fabricated solar-powered cooler had a lesser weight loss, only loosing 2.8% weight compared with 5% weight loss for the conventional field shed storage. The results are concurrent with those reported by Urja, (2016) where loss in weight of mangoes was lower (3.1%) in cold storage when compared to 14.5% in storage at ambient condition. The same results were reported by Kitinoja and Thompson, (2010) where the fresh produce could be stored for long time because they lost less weight and ripened more slowly. The results show a slight difference in the loss of weight for all the produce for the two storage methods. Produce under conventional storage method had incurred higher amount of weight loss compared to those under solar power cooler.

The physiological loss of weight for French beans is a result of both the evaporation of water and respiratory losses (Olosunde *et al*., 2015). Water evapotranspiration depends on the atmospheric temperature and relative humidity within the store (Dzivama, 2000). The less loss in weight recorded in produce within the solar powered cooler was due to low temperature and high relative humidity since the solar powered cooler was characterized by high humidity and low temperature. According to Besadiya *et al*., (2013) low air temperature results in less water vapor held, thus slow respiration and senescence rates and this results in prolonged storage life of both vegetables. Olosunde *et al*. (2015) stated that low temperature reduces respiratory activity while high relative humidity reduces the rate of evaporation from the produce. Produce stored in these passive evaporative coolers has a longer shelf life than produce kept at ambient conditions. Kitinoja and Thompson. (2010) working with tomatoes and peppers reported less losses in weight, slow ripening process and long shelf life. At harvesting the produce contains field heat and respiratory heat meaning that at initial stage there is field heat within the produce in both conventional and solar powered cooler. However, as the storage period progressed, produce in solar powered cooler did not pick up the heat and generated less heat through respiration due to reduction in respiratory activity. In conventional storage method characterized by high ambient heat, the French beans reabsorbed heat from the atmosphere while the high temperature enhanced the process of respiration. The two situations within the two methods accounts for the differences in the loss of weight.

The study has revealed that fabricated solar-powered cooler was more efficient than conventional field shed in maintaining produce temperature during storage. French beans stored under conventional cooling had increase of 18% in temperature in four hours while those stored in the fabricated solar-powered cooler only had 7% increase in temperature. The increase in temperature could be because of physiological factors such as respiration that results in heat emission that increase temperature (Sanchez-Mata, 2003). Vegetables are mostly harvested under ambient temperature of a range of 25 to 35^{o}C and under these conditions the respiration rate is high and therefore there is increase in temperature (Basediya *et al*., 2013). Temperature is the degree of hotness or coldness of a material and influences the shelf life of vegetables and exposure of the produce to extreme temperatures results in increased rate of respiration (Liberty *et al*. (2013). Temperature and relative humidity are aspects that must be considered when handling perishable produce.

The metabolism process in perishable horticultural products continues after harvesting due to senescence, and poor environmental conditions. Therefore, preservation of these produce demands a restricted minimum temperature (Chandra *et al*., 1999; Basediya *et al*., 2013). Therefore, solar powered cooling system becomes an efficient and cost-effective means of temperature reduction and at the same time increasing the relative humidity in storage space (Susan and Durward, 1995). This is because vegetables such as French beans require high relative humidity and low temperature which is achievable through the use of solar powered cooling system. From the results, solar powered cooling system had on average higher cooling efficiency when compared to conventional cooling method. This is as a result of low temperature and high humidity within the solar powered cooler. The cooler temperature was maintained below 19.6^{o}C with higher relative humidity. Therefore, the result of French beans quality was enhanced in solar powered cooler compared with conventional shade.

French bean samples stored in conventional cooling system accumulated more CO_2 and less oxygen compared with those in solar-powered e cooler. The difference CO_2 accumulation can be attributed to the efficiency of the CO_2 sensors installed in the solar-powered cooler to sense high CO_2 levels and trigger the fans to expel excess CO_2 from the produce chamber. The oxygen inside the system is consumed by the produce as it respires, and CO_2 is released such that the volume of oxygen reduces and the volume of CO_2 increases. The high amount of CO_2 within the conventional cooler is an indication of rapid respiration process that influences the quality of fresh produce like French beans (Kader and Yehoshua, 2000). The accumulation of CO_2 around the produce cause rapid deterioration of the produce by causing bad flavor, internal breakdown, and other abnormal physiological conditions (Silva, 2008). According to Kader *et al*., (1989) exposure of a commodity to high levels of CO_2 above the limits it can tolerate results in increased anaerobic respiration which in turn causes buildup of ethanol and acetaldehyde that causes off-flavors. Vegetables such as French beans have high respiration rates and an increase in the amount of CO_2 released may have an effect on the shelf life of the produce. Conventional storage systems are characterized by high temperature conditions that lead to faster respiration such that an increase in temperature of $10^{o}C$ doubles the process of respiration (Silva, 2008).

6.6 Conclusion

A fabricated solar-powered prototype cooler maintains and reduces the produce temperature, maintains the balance between carbon dioxide and oxygen, and reduces the metabolic activities of French beans along the supply chain thereby enhancing the shelf life and quality of the product.

CHAPTER SEVEN
GENERAL DISCUSION, CONCLUSION AND RECOMMENDATIONS

7.1 General Discussion

The major characteristics of farmers covered in the survey were distribution of farmers by gender, educational level, marital status and farmers' age. Results show that majority of the interviewed farmers were male implying that French bean production in the two regions was dominated by males. This could be due to the fact that French bean production is labor intensive (Usman *et al*., 2016). This finding is inconsistent with many findings which have reported women as the leaders in agricultural activities. Majority of the farmers being in the ages of 41 -50 years shows that they are in their active age of agricultural production and are enthusiastic about agricultural production in order to improve the living standard of their households (Siri *et al*., 2012). The interviewed farmers had different levels of education with majority having attained the basic level of the Kenya Certificate of Secondary Education. The level of education positively correlated with the knowledge and understanding of the importance of cold chain management practices. This finding is consistent with those of other earlier studies. Education enables farmers to make choices based on their decision as well as work together with ease with other farmers (Martey et al., 2012). Educated farmers have better skills and implement current technologies and invest in post-harvesting technologies to avoid losses (Garikai 2014).

Majority of the interviewed farmers did not wash their produce because of the stringent rules on post-harvest wash as outlined in the Food Safety Standards that most exporters are expected to comply with. GlobalG.A.P has strict control on the quality of water to be used to wash fresh produce, such water must be of portable/drinkable quality, a requirement that may not be achieved by most of the small holder farmers. Majrity of the farmers harvested French beans in the morning.

Harvesting time impacts positively or negatively to losses associated with post-harvest. Morning hours is characterized by high humidity and low temperatures while in the afternoon, the weather is characterized by high temperatures, and high evaporation resulting in less turgid and shriveled produce (Kereth et al., 2013). From the survey, many farmers had cooling storage facilities that helped in ensuring post-harvest losses associated with high temperatures are reduced.

Delay in cooling fresh vegetables like French beans affects dry matter, carbohydrates, crude fiber, proteins, ashes, and energy value while cooling immediately after harvesting results in little change in moisture loss, weight loss, gross energy and change in and nutritional contents. A loss in weight of about 5% of green beans is considered unacceptable for sale (Yagizet al, 2010). Therefore, an appropriate temperature management between harvesting and marketing is an effective way to preserve the product (Arahet al., 2015). Keeping vegetables harvested at low temperatures of about 20^{o}C slows down the metabolic activity therefore; cooling interruption of even one-hour results in one day loss of shelf life. The changes in protein content due to loss of water are because of the water-soluble nitrogen compounds. In general, average protein content was high in samples harvested late in the afternoon, this could be attributed to results from photosynthesis process in the mid-morning hours.

Harvesting time and time before cooling (pre-cooling duration) affected the population of microorganisms isolated. The availability of the microorganisms within the French bean samples directly reflects on the sanitation of cultivation, harvesting, storage processes of the produce (Eni, *et al*., 2010). For instance, the high population of *Staphylococcus aureus* realized in samples harvested early morning may be attributed to poor personal hygiene of food handlers. The high density of bacterial pathogens from the presents study are similar to those described by Eni *et al*., (2010) where bacterial population as high as 9.9×10^{6} was reported. Harvesting time and storage temperature are important factors influencing the population of bacteria in French beans (Luo *et al*., 2010). During harvesting, and immediately after harvesting, it is vital to minimize the wounds and bruising that may act as entry points for these pathogens. Fungi primarily enter fresh vegetables through the formation of germ tube that penetrates the cuticle and epidermis (Barth *et al*., 2009). Management of microbial contamination with regards to food safety management calls for robust systems based on HACCP principles, which works to identify all the risks and have in place measures to reduce these risks in the supply chain.

Different cooling methods have different effects on the quality of the produce. In the current study we had conventional cooling system and solar power cooling systems. Produce in solar powered cooling system characterized by low temperature and high humidity had least weight loss compared with those stored in conventional systems. This results closely mirror those reported by Urja, (2016) where loss in weight of mangoes was lower (3.1%) in cold storage when compared to 14.5% in storage at ambient condition. Produce under conventional storage method had accumulated high amount of weight loss compared to those under solar power cooler. The loss in weight is a result of both the evaporation of water and respiratory losses (Olosunde *et al*., 2015). The produce temperature between the two storage systems significantly differed. In conventional cooling system, the product temperature was lower in the morning hours and increased in the afternoon. However, in the solar powered cooling system there was no substantial increase in produce temperature. The increase in temperature could be because of physiological factors such as respiration that results in heat emission that increase temperature (Sanchez-Mata, 2003). Temperature and relative humidity are an aspect that must be considered when handling perishable produce. Any method that that reduces relative humidity between the environment and the produce increases the temperature results in increased produce temperature and higher water loss (Liberty *et al*., 2013). French bean samples stored in conventional cooling system accumulated more CO_2 and less oxygen compared with those in solar cooling system. The oxygen inside the system is consumed by the produce as it respires, and CO_2 is released such that the volume of oxygen reduces and the volume of CO_2 increases. The high amount of CO_2 within the conventional cooler is an indication of rapid respiration process that influences the quality of fresh produce like French beans (Kader and Yehoshua, 2000).

7.2 Conclusion

Based on the survey results French bean farmers had fundamental knowledge about post-harvest handling practices of French bean. Products like French beans require low temperatures and high humidity, factors that are not easily achieved by the small-scale farmers. The study indicated that many respondents had cooling storage facility before transporting to the respective customers. This ensured reduced post-harvest losses associated with high temperatures. High humidity is essential during storage in order to minimize deterioration of quality of products associated with respiration. However, extended period of humidity may provide conducive environment for the growth of pathogens that may further reduce the quality of French beans.

Harvesting time and duration to start of cooling have a significant effect on the shelf life and overall quality of French beans. In general, the longer the duration to cooling and late harvesting time, the faster the deterioration of the French bean pods. French beans harvested in the afternoon may have higher weight loss, but with increased protein, carbohydrate and ash content. Quality and improved shelf life of French beans starts immediately after harvesting. It is therefore important for farmers to harvest French beans early in the morning and cool them as soon as possible for improved quality.

The results show that harvesting time and time before cooling (precooling duration) significantly affected the population of microorganisms isolated. The microorganisms isolated from the French bean samples directly reflect the sanitation of the processes during the handling of French beans. Harvesting time and storage temperature influence the quality of fresh produce. The results confirm that total microbes contaminating French beans were exceptionally high in samples harvested early in the morning but reduced when the samples were harvested as from 9am

Solar-powered cooler maintains and reduces the produce temperature, increases the relative humidity, maintains the equilibrium between carbon dioxide and oxygen, and reduces the respiratory activity of the French beans within the optimum level of the storage thereby keeping the produce fresh with prolonged shelf life.

7.3 Recommendations

i. Irrigation water quality should be regularly monitored for presence of microbial contamination.
ii. Irrigation methods that get irrigation water into direct contact with edible part of the crop should be avoided.
iii. French beans should be harvested in the morning before temperatures rise.
iv. Food handlers must be trained on basic food hygiene principles before starting work.
v. French bean harvesters should be provided with hand gloves to minimize the risk of contamination that is as a result of handlers' personal hygiene.
vi. Fabricated solar powered coolers should be adopted for use by smallholder farmers to maintain cold chain and reduce food waste along the supply chain.

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APPENDIX

Annex 1. 1: Questionnaire to assess the current knowledge and extent of use of cold chain management practices among small scale French bean farmers in Kenya

Date of interview..

Name of enumerator...

Sub-county.................................. Ward...................................... Village……………………

GPS coordinates: Southings.................... Easting....................

We are a team of students from the University of Nairobi carrying out a study to assess the current knowledge and extent of use of cold chain among French bean supply chain in Kajiado County. This questionnaire is intended to collect information which will be used as a basis to improve cold chain management in Kajiado County and Kenya.

Social economic characteristics

a) Name of respondent…………………………………………………………..

b) Gender of respondent

1. Male []   2. Female []

c) Age of respondent.

1) Under 18 years old []
2) 19 to 30 years old []
3) 31 to 40 years old []
4) 41 to 50 years old []
5) Over 51 years old []

d) Marital status of respondents

1) Married []
2) Never married/ single []
3) Widowed []
4) Divorced []

e) Level of study of respondents

1) Pre-primary/primary []
2) Secondary/vocational training, []
3) Post-secondary-college/university []

f) Are you the one involved in day-to-day operations and management at this farm?

1. Yes [] 2. No [ ]

g) If not, what is the name of the person who is involved in day-to-day operations and management?

…………………………………………………………………………………………………..

h) What education level has been attained by the person who is involved in day-to-day operations and management?

1) Pre-primary/primary []
2) Secondary/vocational training, []
3) Post-secondary-college/university []

i) What is the main occupation of the person who is involved in day-to-day operations and management?
1) Salaried employment []
2) Own business/ professional []
3) Casual labourer []
4) Not employed []

j) What is the total land size of this farm?
1) Less than one acre []
2) More than one acre but less than five acres []
3) More than five acres but less than ten acres []
4) More than ten acres []

k) Of the total land size, what proportion is being currently used for French beans production?
1) Less than 25 % []
2) 26 % to 50 % []
3) 51 % to 75 % []
4) More than 75 % []

l) On average, what quantity of French beans do you harvest per season from this farm?

....

m) Are you contracted by any organization/ exporter/ farmer group?
1) Yes, I am contracted []
2) No, I am freelance []

n) On average, how many seasons in a year do you produce French beans?
1) 1 season in a year []
2) 2 seasons in a year []
3) 3 seasons in a year []

o) At what time do you normally harvest French beans?
1) During the night and before 6 AM []
2) Between 6 AM and 9 AM []
3) Between 9 AM and Noon []
4) Between Noon and 3 PM []
5) Between 3 PM and 6 PM []

p) Do you measure the temperature of French beans after harvesting?

1. Yes [] 2. No []

q) What temperatures do you target?
1) Less than 5ºC []
2) 6ºC to 10ºC []
3) 11ºC to 15ºC []
4) 16ºC to 20ºC []
5) More than 21ºC []

r) If the temperatures exceed the target, what do you do?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………..

s) Do you wash French beans after harvesting?

1. Yes [] 2. No []

t) If you wash French beans after harvesting, what do you add to the washing water?

…………………………………………………………………………………………………

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………………………………………………………………………………..

u) Do you store harvested French beans after harvesting?

1. Yes []   2. No []

v) For how long do you store the French beans on average?
1) Less than one hour []
2) 1 hr to 6 hrs []
3) 6 hrs to 12 hrs []
4) 12 hrs to 24 hrs []
5) More than 24 hrs []

w) Where do you deliver the French beans to?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………………………………..

x) Are you in any farmer group/ farmer organization?

1. Yes []   2. No []

y) Do you collectively store/ cool harvested French beans in the farmer groups/ farmer organization?

1. Yes []   2. No []

z) What quality does the buyer demand?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

………………………………………………………………………………..

aa) What do you do to ensure you meet the demanded quality?

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………………………………………………………………………………

……………………………………………………………………………..

bb) Have you ever used a charcoal cooler to store and cool French beans?

1. Yes []		2. No []

cc) How had you constructed the charcoal cooler?
Floor………………………………………………………………………………………..

Roof………………………………………………………………………………………...

Walls………………………………………………………………………………………..

Presence of humidifiers……………………………………………………………………..

dd) In your perception, was the charcoal cooler effective?

1. Yes []		2. No []

ee) What do you think could be done to improve the charcoal cooler?

……………………………………………………………………………………………

……………………………………………………………………………………………

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Thank you for participating in the survey.