MANAGEMENT OF WARE POTATO SPROUTING DURING LONG TERM STORAGE IN THE TROPICAL CONDITIONS OF KENYA

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DECLARATION

I declare that this thesis is my original work. To the best of my knowledge, the work presented here has not been presented for an award of any degree in any other university.

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DEDICATION

To God Almighty for His sufficient grace, guidance, protection and provision during the study period.

And

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SYMBOLS AND ABBREVIATIONS

CIPC	Isopropyl-N-phenylcarbamate (Chloropropham)
CA	Controlled Atmosphere
DMN	Dimethylnaphthalene
FAOSTAT	Food and Agriculture Organization Statistics
FAO	Food and Agriculture Organization
MOA	Ministry of Agriculture
MAP	Modified Atmosphere Packaging
NPCK	National Potato Council of Kenya
WHO	World Health Organisation
PE	Polyethylene
mm	Millimeters
$t\ ha^{-1}$	Tonnes per hectare
ppm	Parts Per Million
DAP	Diammonium phosphate
%	Percentage
HD	High Density
LD	Low Density
CO_2	Carbon dioxide
O_2	Oxygen
$mg\ kg^{-1}$	milligrams per kilogram
CIP	International Potato Cent

ABSTRACT

Potato is an important crop in Kenya. However, its long term storage is low owing to a number of constraints. Amongst these is inadequate post-harvest handling techniques and short dormancy of popular cultivars leading to premature sprouting. There is a window of six months between harvests and most of the cultivars have dormancy period of 1-3 months therefore, management of sprouting has to be an integral part of short-term storage as well. Use of sprout suppressants to control premature sprouting of ware potato is therefore an attractive proposition. Researchers around the world and especially in temperate countries have developed sprout suppressing compounds but their effects under tropical conditions is not well known. This study was designed to determine the effectiveness of five sprout suppressants on three potato cultivars adapted to the ecologies of Kenya. Four separate experiments were carried out with the following specific objectives; to determine the effect of: (i) post-harvest application of Isopropyl-N-phenylcarbamate (CIPC), peppermint oil and 1,4-Dimethylnaphthalene (DMN) on ware potato storability (ii) storage temperature on the efficiency of sprout suppressants (iii) pre-harvest foliar application of Paclobutrazol and Ethephon on sprouting of ware potato tubers in storage (iv) packaging materials on ware potato quality during short-term storage. The study was conducted on three potato cultivars with varying levels of dormancy; Shangi (30 days), Asante (60 days) and Kenya Mpya (60 days). Four experiments were conducted separately and the parameters recorded were dormancy length, weight loss, sprouting and sprout growth, tuber rotting and tuber greening. In experiment 1, the results showed that sprout suppressants minimized the detrimental effects of sprouting thereby improving storability of ware potatoes. CIPC recorded the best sprout suppression with over 75% sprout suppression in all cultivars. In experiment 2, storage temperature influenced the efficacy of sprout suppressants. Sprout suppressants were more effective in delaying sprout emergence and subsequent sprout growth under cold storage compared to ambient storage in all the cultivars with CIPC and DMN recording up to 100% sprouting suppression. In experiment 3, pre-harvest applied sprout suppressants were effective in delaying dormancy end when tubers were stored at ambient storage. However, at cold storage, the treatments did not have an effect on dormancy period in all the cultivars. Among cultivars, Kenya Mpya was more responsive to the treatments compared to Shangi and Asante. In experiment 4, packaging and the type of packaging material affected the shelf life of ware potatoes. Packaging reduced post-harvest losses due to weight loss and tuber greening but increased the rate of sprouting and decay

incidences. Low density black polyethylene bag emerged as the best method for ware potato packaging.

CIPC, DMN, peppermint oil and Paclobutrazol are effective sprout suppressant whose application in potato warehousing will contribute to the economic well being of Kenyans.

Key words: Potato, postharvest loss, tropical environment, sprout suppressant, sprout control

CHAPTER ONE: GENERAL INTRODUCTION

1.1 BACKGROUND INFORMATION

The potato (*Solanum tuberosum*) is an important tuber crop that is ranked as the world's fourth largest food crop after wheat, rice and maize in terms of production and area covered (Muthoni and Nyamongo, 2009). Its adaptation to a wide range of climatic conditions as well as soil types makes it to be widely cultivated (Paul et al., 2016). The crop is produced in nearly 150 countries worldwide with global total crop production exceeding 385 million metric tons in 2014 (FAOSTAT, 2015). Potato is an important crop whose production is increasing rapidly in developing countries. Total production in Africa accounted for 30 million tons in 2013 which was about 8.1% of the global production (FAOSTAT, 2015). This growth attests to the important role the potato crop plays in meeting the needs of the population.

In Kenya, potato is one of the important crops that plays a dual role as a food and cash crop and ranks second after maize in terms of utilization (National Potato Council of Kenya (NPCK), 2015; Kaguongo et al., 2014). It has great contribution to the economic growth of the country. The potato industry employs approximately 2.5 million people directly and indirectly (Abong and Kabira, 2013). The potato crop plays a critical role in poverty alleviation through job creation, income generation to farmers and marketers and has great potential to improving food security given its high productivity (Kaguongo et al., 2014; Muthoni et al., 2013). The potato industry has been undergoing major changes and increased production over time not only globally but also in Kenya. According to the Food and Agriculture Organisation (FAO) (2014) statistics, potato production has been variable but with a general increase in area under the crop from 2,400 hectares producing 16,000 metric tonnes in 1939 to 128,000 hectares producing 125,256 tons in 2014. Nearly all the potatoes produced in Kenya are consumed locally with approximately 98% being sold for fresh consumption and only 2% for processing (Janssens et al., 2013). Although it is an important crop, post harvest losses remain high at 12.8% which necessitates the need for intervention. The national average production is 7.7 t ha^{-1} in Kenya which is low compared to the global average of 17.4 t ha^{-1} (Janssens et al., 2013; Sanginga, 2015). However, it is possible to realize 25 t ha^{-1} reported by professional farmers using sound agricultural practices and

certified seeds (Kaguongo et al., 2014). The crop is grown annually by approximately 800,000 farmers with an annual value of 46 billion KSH at consumer level (NPCK, 2015; Abong and Kabira, 2013). Eighty three percent of potato growers are small scale with an average plot size allocated to potato production being 0.2-0.4 ha while approximately 17% of potato plots belong to larger-scale farmers dedicating 2 to10 hectares to the crop (Janssens et al., 2013). It is mainly cultivated in the high altitude areas between 1500 and 3000 meters above sea level with mean temperatures of 15-24^{o}C and mean rainfall of 1200-1800mm, found mostly in Central, Rift Valley, Western, Nyanza, Eastern and Coast parts of Kenya (MoA, 2010; NPCK, 2015). Central Kenya accounts for more than 53% of the country's potato production and nearly all the counties produce some potatoes, with Nyandarua County, being the largest and most diversified potato producing area. In Eastern part of Kenya, the main growing region is Meru County. In Rift Valley, potatoes are grown in Dundori, Mau Narok, Nakuru (Molo), and in the western highlands of Kericho, Bomet and Uasin Gishu counties. The main varieties grown include: Ambition, Annet, Arizona, Arnova, Asante, Caruso, Connet, Derby, Desiree, Destiny, Dutch Robjin, El- Mundo, Faluka, Jelly, Kenya Baraka, Kenya Karibu, Kenya Mavuno, Kenya Mpya, Kenya Sifa, Kerr's Pink, Manitou, Markies, Mayan Gold, Musica, Purple Gold, Royal, Rumba, Rudolph, Sagitta, Sarpo Mira, Saviola, Shangi, Sherekea , Taurus, Tigoni, Toluca (NPCK, 2015).

Potato tubers are very popular due to their affordability, availability, nutrition, ease of cooking and palatability. It is a great source of protein, vitamin C, zinc, carbohydrates and iron. Despite its importance to the economy and general well being of Kenyans, the potato crop is faced with challenges along the value chain. Among the challenges, high post harvest losses further compounds the problem of low production, climate change effects, pest and diseases among others. High post harvest losses in Kenya results from; limited storage technologies which is aggravated by high ambient storage temperatures in farmers and traders stores, poor handling during harvesting, sorting, grading, transporting and storage. In addition, most of the locally grown potato cultivars have short-medium dormancy length.

The quantity of potatoes produced in the country barely meets the needs of the increasing population. The accelerating pace of climate change coupled with an increasing population threatens Kenya's food security; with a significant proportion of rural communities constantly being faced with food deficits likely to be the most seriously affected (MoA,

2010). Present trends indicate that future population and economic growth will require a doubling of current food production. Post harvest problems in terms of storage and marketing of potatoes already exist and increasing production will likely make it more pronounced.

1.2 PROBLEM STATEMENT

High post harvest losses especially at the storage level is a major problem that has virtually received no intervention in Kenya. Kaguongo et al. (2014) reported post-harvest losses of potatoes to be 12.8%-25% which further compounds the problem of food insecurity. Most of ware potato quality loss in storage has been due to excessive sprouting, weight loss, rotting, greening and pest attack. This loss in quality affects their marketability leading to loss of income. Sprouting is a major problem limiting long-term storage of ware potatoes with a potential to cause 100% market loss as flaccid sprouty tubers are less marketable. It not only leads to loss of saleable tubers but also increases weight loss and shriveling. Ninety percent of weight loss occurs due to evaporation and sprout growth is a major contributor to evaporation (Mehta et al., 2010; Kabira and Lemanga, 2003; Gautam et al., 2013).

The most preferred cultivar is Shangi due to its high yields, faster growth and short cooking time. However, tubers start sprouting within a month after harvest therefore it is not suitable for long-term storage. As a result, Shangi tubers are sold cheaply soon after harvest as farmers avoid storage losses.

Low temperature storage (2-4^{o}C) has been reported to be ideal for storage of potato tubers since it minimises sprouting, weight loss and rotting incidences (Burton and Wilson, 1978). However due to the problem of cold induced sweetening of tubers that affects their palatability, potatoes are stored at a higher temperature of 8-12^{o}C (Isherwood, 1973; Burton and Wilson, 1978; Matsuura-Endo et al., 2006). However, to achieve this temperature in tropical environment of Kenya which is characterized by high mean temperature of 20 – 28^{o}C requires cold storage technique. This is not a feasible method of storage in developing countries due to the high cost associated. Additionally, farmers do not have access to cold storage facilities at the farm level. In most cases, farmers sell most of their produce immediately after harvest and the remaining tubers are stored in their farm houses. Despite temperature of 8-12^{o}C being ideal for storage of ware potato, it is not a long-term solution to the problem of sprouting. With storage time, sprout development occurs hence the need to

have a more long-term solution. Sprout suppressants have been advocated for effective long term storage of tubers meant for processing and table consumption.

In Kenya, no work has been done to investigate the effects of sprout suppressant and their efficacy in different storage conditions. Potato cultivars vary in their response to treatments with sprout suppressants hence the need to investigate cultivar of varying dormancy length. Packaging plays an important role in keeping food safe as well as maintaining quality of packaged products. There are no proper packaging materials designed for different crops available. Baskets, polyethylene bags among others are simply used to pack goods of all types without special attention being given to their suitability for the specific crops (Arinze, 2005). According to World Health Organization, significant food losses occurs in many third world countries and 30% to 50% of food produced in these countries goes to waste because of insufficient means of preservation, protection, storage and transportation.

1.3 JUSTIFICATION

Climate change has led to a reduction in cereal production but tuber crops can effectively substitute them (MoA, 2010). According to the national root and tuber policy, potato is one of the crops that provide great potential for ensuring food security for the majority of Kenyans (MoA, 2010) therefore; post harvest storage losses must be curbed. All potato tubers have a natural dormancy period which varies according to genotypes. Beyond the rest period, sprouting becomes a major cause of storage losses limiting potato storability.

The demand for potato is on the rise due to the increasing urbanization, lifestyle change and need for convenient foods that have led to increased uptake of processed potato products like chips, potato bhajias and crisps. This provides a ready market for potato growers. However, post harvest losses due to sprouting and poor storage techniques threaten supply of this precious commodity. If adequate sprout suppression is not maintained, there will be significant reduction in potato quality and the ability to store for extended periods of time will diminish. Lack of well developed post harvest storage techniques for long term storage of potato tubers have led to low supply during non-production months. Effective control of sprouting is therefore a fundamental requirement in managing ware potato quality during storage. In Kenya, harvesting of potatoes is normally in hot months of January- February and August- September. At harvest, the supply is normally greater than the market demand and

the absence of adequate storage technology is heavily felt. Due to seasonality of production, limitedness of alternative markets, absence of cold storage system and lack of treatment with sprout inhibitors usually result in market oversupply; accompanied by heavy price cut throughout the major harvesting months. Prices start to rise in March and are virtually triple between May–July and at the same time; the demand is greater than supply. Most potato cultivars grown in Kenya are known to have short-medium dormancy period of 1-2 months (NPCK, 2015). The current most preferred cultivar (Shangi) begins to sprout about 3-4 weeks after harvest. Therefore, management of sprouting has to be an integral part of short-term storage as well. Potato sprout suppressants such as Isopropyl-N-phenylcarbamate (CIPC), Ethylene, peppermint, dimethylnaphthalene (DMN), Maleic hydrazide (MH), Hydrogen peroxide, Carvone, Diisopropylnaphthalene are usually applied to suppress sprouting during long-term storage (Prange et al., 1997; Kleinkopf et al., 2003; Afek et al., 2000). However, these substances have rarely been tried in Kenya. Besides, there is scarcity of information in the literature on the efficacy of these sprout suppressants under tropical environment. Curbing post harvest losses by the use of sprout suppressants in Kenya will; help the farmers store their produce for high prices at the appropriate time, help spread supply from one harvest to the next, increase food availability and improve income to farmers and traders.

A lot of research has been conducted on exogenously applied ethylene and has resulted in contradictory reports. It has been shown to promote or delay sprouting and sprout growth (Daniels-Lake et al., 2005; Suttle, 1998; Bufler, 2009). In addition, it has been reported to cause darkening of fried potato products when used continuously as a sprout suppressant (Prange et al., 2005). On the other hand, endogenous ethylene has been reported as a potent growth regulator (Suttle, 2004) though the information available is scanty. The current study will add to literature the effectiveness of ethylene when applied as a preharvest foliar spray under field conditions of tropical environment in extending the storage life of potatoes. Moreover, the problems of sprout growth retardation and prolonging dormancy in potato tubers by chemical treatment would be greatly simplified if growth substance could be sprayed on the foliage while the plants is still growing in the field.

Unlike the developed countries, developing countries lacks relevant knowledge of the techniques of packing and storage of different crops (Arinze, 2005). Perishable crops naturally store poorly and record much higher losses than the non-perishables and, of course,

the longer the period of storage the greater the loss. Over the years in Kenya, ware potatoes have been packaged in polyethylene bags, nylon gunny sacks, khaki bags, buckets and net bags in the retail market. However, the effect of these packaging materials on quality changes in potato tubers is unknown. To help minimise food waste throughout the supply chain and save cost, an optimum level of packaging is required. Given that Potatoes are important part of human nutrition, the current packaging materials used needs to be evaluated in order to minimize losses and maintain quality (both physical and nutrition) to acceptable consumer level.

1.4 OBJECTIVES

1.4.1 Overall objective

To increase storage life and reduce postharvest loss of ware potato by reducing sprouting

1.4.2 Specific objectives

To determine the effects of

i. To determine the effect of Isopropyl-N-phenylcarbamate (CIPC), peppermint oil and Dimethylnaphthalene (DMN) on ware potato sprouting.

ii. To determine the effect of storage temperature on the efficiency of sprout suppressants

iii. To determine the effect of preharvest foliar application of paclobutrazol and Ethephon on sprouting of stored ware potato tubers at different storage temperatures.

iv. To determine the effect of packaging materials on ware potato quality during short-term storage

CHAPTER TWO: LITERATURE REVIEW

2.1 The potato crop and its

2.1.1 Origin

Potato is an herbaceous perennial crop grown as an annual crop belonging to the solanaceae family (Horton, 1987). It is native to South America where it has been consumed for over 8000 years. The potato crop was introduced to Europe in 16th century and widely spread throughout the continent by 19th century. It was imported from Europe to Africa by missionaries and thereafter by colonial administrators in the 19th Century (MoA, 2010). The English settlers initially introduced the crop in Kiambu, Murang'a and Nyeri districts primarily for home consumption and later for export (Durr and Lorenzl, 1980). Indigenous Kenyan farmers started potato cultivation in 1920 and entered the export market in 1923; the main variety grown during that time was Kerr's Pink (Durr and Lorenzl, 1980).

Potato is propagated by tubers. The tuber, which is an enlarged underground stem, is the edible part of the potato plant. Potato tubers come in different colours but the most common are red and white. It has a short vegetative cycle (3-4 months) that make it possible to harvest 3 crops per year therefore has a high potential for addressing food crisis. Potatoes are widely adapted and can be grown at altitudes of up to 4 300 m and in a variety of climatic conditions (FAO, 2008).

2.1.2 Economic importance

Potato is very important in the Kenyan agricultural sector. Its importance is attributed to its high nutritive value, good productivity and good processing qualities for starch, flour, bread, soap, alcohol, weaning foods and animal feed (MoA, 2010).

Virtually all of potatoes produced in Kenya are consumed locally, at an average rate of approximately 25 kg per capita a year ((FAO, 2008)). While in some African countries potato is considered a "poor person's food", in Kenya it is considered a high quality and important food item (FAO, 2008). They generate income to farmers, play a significant role in Kenyan food security as well as create employment opportunities. The potato industry employs thousands as market agents, transporters, processors, vendors and researchers (Abong and

Kabira, 2013). Potatoes are commonly consumed in the fresh forms but change of eating habits especially in the urban centers has led to increased consumption of processed products. Processing and marketing of chips has become a major commercial activity in Kenya's urban centers as evidenced by the increasing number of fast food kiosks. It is estimated that there are over 40 local processors of crisps; Nairobi alone has over 800 restaurants selling chips (MoA, 2010). Industrial level processing of Irish potatoes is mainly in the production of starch and snack foods such as crisps, chevda, frozen potato chips and dried potato cubes (MoA, 2010). In most developing countries, the growth in urban populations and incomes and the diversification of diets have led to rising demand for potatoes from the fast food, snack and convenience food industries ((FAO, 2008)). With its adaptability to a wide range of uses, the potato has a potentially important role to play in the food systems of developing countries (FAO, 2008). Potatoes processing began with the establishment of vegetable dehydration plants in Kerugoya and Karatina to meet the needs of the British armies in Northern Africa and Asia (MoA, 2010). In order to meet the increased demand for processed products, higher yielding and disease resistant varieties, were imported and new cultivation areas in Meru and Molo were opened up (MoA, 2010).

2.1.3 Nutritional value of potato

The potato tuber is a good source of dietary energy, some micronutrients especially vitamin C, protein, iron, vitamins B1, B3 and B6; minerals such as potassium, phosphorus and magnesium; and contains folate, pantothenic acid and riboflavin, dietary antioxidants and an excellent source of dietary fibre, which benefits health ((FAO, 2008)). Potatoes can be consumed in many different ways, either fresh or processed. Possible cooking methods include baking, roasting, boiling, stewing, frying and manufacture of products such as crisps, French fries and Bhajia.

2.2 Challenges Facing the Potato Industry in Kenya

Despite the high potential to contribute in improving welfare of many Kenyans, potato sector faces numerous problems ranging from low production of less than 10t/ha against a potential of 40t/ha (NPCK, 2015). Below are the factors that have contributed to the low production and post harvest losses.

There is limited access to good quality planting material. Farmers' results to use seeds saved from previous harvest, buying from the local market or neighbors as well as exchange of seeds among farmers (Riungu, 2011). If the seeds are infected, the problem is passed on to the next season. Additionally, Kenya produces less than 1% of the domestic certified seed demand (Muthoni et al., 2013).

A study by Muthoni et al. (2013) revealed that diseases such as bacterial wilts and late blight not only resulted to low yields but also huge post harvest losses. The high cost of fungicides and fertilizer makes it difficult for some farmers to follow the recommended application rates hence affects the yields (Riungu, 2011).

Soils in growing areas are exhausted due to many factors such as climate change, continuous cultivation, and inadequate use of fertilizer. Population density limits crop rotation. Not many farmers can practice crop rotation for the recommended one and a half years due to scarcity of land (Riungu, 2011).

Overreliance on rainfall has led to seasonality of production resulting to market gluts and scarcity periods (Janssens et al., 2013)

Major marketing constraints are due to packaging and price fluctuation. Nearly all farmers pack their potatoes in extended bags (Muthoni et al., 2013). Traders buy potatoes on per bag basis and not weight and this has condemned farmers to exploitation by brokers. Price fluctuation is due to seasonality of the crop leading to surplus and lean periods (Muthoni et al., 2013). Potato producers have limited power to determine selling prices for their produce due to poor storability of potatoes as well as limited on-farm storage facilities (Muthoni et al., 2013). Studies indicate that most farmers harvest potatoes and sell them almost immediately due to lack of storage capacity (Durr and Lorenzl, 1980). Storage challenges such as limited on-farm storage facilities and poor keeping quality of tubers deny farmers bargaining position leading to sale of produce at low prices.

Storage of ware potato for long period (2-6 months) is not a common practice in Kenya. Most of the small scale farmers do not have appropriate storage structures for their potato. Most of them store tubers in wooden stores with corrugated iron sheets tops. No post harvest

treatment for long-term storage is applied to the stored tubers. Losses in these structure average 20% in two months (Janssens et al., 2013).

2.3 Post harvest losses

Post-harvest loss refers to changes in quality and quantity of a product between harvest and consumption that hinders its consumption by humans (Fallik and Aharoni, 2004). A quantitative loss refers to losses in weight or volume while qualitative loss results from physiological changes that affect nutritive value, consumer acceptability and palatability of a product (Kader, 2004; Snowden, 2008). Quantitative losses of potato tubers are due to bruising, rotting, greening, sprouting, pest and diseases infestation. Loss in quantity and quality can subsequently result to economic losses due to lost market value (Hodges et al., 2011). Post harvest loses varies considerably among commodities, area of production and season. Developed countries have efficient and effective storage management systems that prolong the shelf life of harvested produce hence the losses are minimal <10% (Hodges et al., 2011; Paliyath et al., 2009). Under tropical conditions where storage facilities are wanting, post harvest losses are reported to be >50% (Paliyath et al., 2009). Post harvest losses in Kenya have previously been estimated at 30% of all stored produce; however the losses can be 100% depending on the severity (MoA, 2010). Potato losses during storage alone are estimated at about 3-10% per month (Durr and Lorenzl, 1980). A post-harvest loss of harvested products is mainly due to biological and environmental factors. Among the biological factors, respiration rate, rates of compositional changes associated with flavor and nutritive value, mechanical injuries, water loss, sprouting, physiological disorders, and pathological breakdown affect storability of potato tubers (Kader, 2004). These biological changes are influenced by external environmental factors such as temperature, relative humidity, air velocity, and atmospheric gas (oxygen, carbon dioxide) composition and sanitation (Kader, 2004).

2.3.1 Storage conditions affecting ware potato quality

Light: Prolonged exposure of ware potato to light causes undesirable formation of green pigmentation due to increased formation of glycoalkaloids (Pavlista, 2001). Tuber greening is influenced by the quality of light, duration of exposure and intensity (Pavlista, 2001). Green

tubers are considered unfit for human consumption. This affects their marketability for fresh consumption.

Temperature: temperature during storage have been reported to influence respiration rate, development of decay causing organism, weight loss, processing quality and wound healing (Kleinkopf, 1995; Wigginton, 1974). Extremely low (below 2^oC) or high temperature can damage potato tubers. Potato tubers freeze at temperature of -1 to 2^oC and frozen tubers lose water and start rotting (Wustman and Struik, 2007). Storage temperature below 5^oC affects chips colour causing them to fry dark due to accumulation of sugars (Kyriacou et al., 2009). On the other hand, too high temperature causes increased rate of respiration and eventual cell death manifested as black hearts (Wustman and Struik, 2007). Respiration increases with increase in temperature above 5^oC and it increases rapidly at temperature above 15^oC (Wustman and Struik, 2007). Weight loss, sprouting and spout growth increases with increase in temperature.

Humidity: high humidity has been reported to shorten the period of endodormancy (Burton, 1989). Weight loss and shrinkage are affected by storage humidity (Aharoni et al., 2007).

Gas composition: the main storage gases that affect tuber quality are Oxygen (O_2) and carbon dioxide (CO_2) concentration. Any Co_2 build up promotes dormancy break (FAO, 1991). Exposure of potato tubers to O_2 levels lower than their tolerance limits and CO_2 levels over their tolerance limits can induce physiological disorders such as black heart (Kader et al., 1989). Oxygen concentration of less than 5% within storage inhibits periderm formation and the wound healing process, increase off flavors, decay and surface moulds (Gachango, 2006). Oxygen concentration of less than 10% within storage has been reported to increase sprouting of potato tubers (Salunkhe and Desai, 1984). Ventilation of storage facilities is therefore important to allow gaseous exchange (O_2 and CO_2), heat and moisture removal (Gachango, 2006).

2.3.2 Post-harvest Loss of Potato tubers

Potato storage presents challenges as the tubers are alive and continue to respire, transpire and undergo biochemical and physiological changes in storage (Hossain and Miah, 2009). Potato tuber contains about 75% water and 25% starch, therefore, is capable of losing the

internal water depending on storage conditions (CIP, 2009). Sprouting and evaporation accounts for 90% of weight loss in tubers while respiration accounts for 3-9% (Mehta, 2004; Kabira and Lemaga, 2003). Weight loss of above 10% renders ware potato unusable due go severity in shriveling (Ezekiel, 2005). Respiration occurs since the tuber is alive and requires the energy to maintain metabolic processes of the tuber (Beukema and Van der Zaag, 1990). When storage temperature is high, respiration of tubers is high. Most of the farmers in Kenya store potato tubers for home consumption and for seeds for the next season for approximately two months. In these two months storage losses are approximated to be 20% (Janssens et al., 2013). Storage losses are influenced by the tubers physiological condition, mechanical damage during harvesting as well as the conditions in storage. These losses are often specified as weight loss, tuber rotting, tuber greening, sprouting and shriveling.

2.4 Ware potato sprouting

At harvest, potato tubers are in a dormant state and will not sprout but as the storage period extends, dormancy is broken and sprout growth begins (Suttle, 2004). Sprouting is the visible growth of shoot meristem tissue in the "eyes" of potato tubers that occurs after end of dormancy ((Daniels and Prange, 2007)). Sprouting is a major factor contributing to both qualitative and quantitative losses of stored ware potato tubers. Dormancy break and the resultant sprout growth are accompanied by various biochemical changes, many of which are deleterious to the nutritional and processing qualities of potatoes (Suttle, 2004).

Sprouting and sprout growth are significant contributors to the weight loss of stored potato tubers (Gautam et al., 2013; Benkeblia et al., 2008; Paul et al., 2016). It has been revealed that the presence of sprouts increases water loss since the epidermis of the sprout is about 100 times more permeable to moisture loss compared to rest of the tuber surface (Benkeblia et al., 2008). The commencement of sprouting and continuous sprout growth increases respiration as well as evaporation (Wustman and Struik, 2007). Sprouting therefore causes rapid rise in physiological weight loss of potato tubers in storage (Paul et al., 2016). In addition, sprouting results in remobilization of storage compounds mainly starch and proteins as sprout tissue is built from the tuber reserves, increased rate of respiration, impedes airflow in a pile and loss of tuber firmness (Daniels and Prange, 2007; Mani et al., 2014; Sonnewald and Sonnewald 2014). These changes are harmful to the nutritional status and quality aspects of potato

tubers. Vitamin C is the main vitamin in potatoes and its content is adversely affected by sprouting (Rezaee et al., 2011). In processing, flaccid tubers do not pass through processing equipment properly (Daniels and Prange, 2007).

2.4.1 Management of sprouting in ware potato during storage

Sprout control is an important part of potato storage. It not only allows for subsequent distribution of potatoes to processors, retail market and restaurants but also supply of a satisfactory product months beyond harvesting. A variety of methods have been suggested for the control of potato sprouting. Low temperature or application of chemical sprout inhibitors are possible methods that can be used to control ware potato sprouting (Frazier et al., 2004).

2.4.1.1 Low temperature storage

Low temperature (2-4^{o}C) is ideal for storage of potato seeds because at this temperature no sprouting can occur. This low temperature is however not suitable for storage of tubers meant for either fresh consumption or processing purposes. If the temperature is too low (2-4^{o}C) it can also result in an increase in reducing sugar content, primarily glucose and fructose within the tuber causing cold induced sweetening (O'Donoghue et al., 1995; Sonnewald, 2001). Higher concentrations of glucose in tubers causes' dark brown colour on processed products such as chips and crisps that gives a bitter taste thereby affecting consumer acceptability(Frazier et al., 2004; Kyriacou et al., 2009; Brown et al., 1990). Since fry color is an important quality factor, low temperature storage is not appropriate for potatoes destined for the processing market. Storage temperatures of 8-12^{o}C is suitable for the storage of ware potato given that this temperature range allows minimum accumulation of reducing sugars in stored potato tubers (Ezekiel et al., 2007). However, this storage temperature favors sprouting and sprout growth following the end of the natural dormancy. This necessitates the use of a potato sprout suppressant for continued sprout control.

2.4.1.2 Sprout suppressants

A range of compounds with sprout suppressing abilities have been reported. Some are commercially available while others require more investigation to be used in potato stores. These compounds are; Isopropyl-N (3-chlorophenyl carabamate) commonly known as CIPC, 1,4-Dimethylnaphthalene (1,4-DMN), Isopropylphenylcarbamate (IPC), Maleic hydrazide

(MH), Carvone, Ethylene, Hydrogen peroxide, Tecnazene, Essential oils (e.g. caraway, peppermint, spearmint, clove oil) and Volatile monoterpenes (Kleinkopf et al., 2003).

2.4.2 Sprout Suppressants of interest in this study

The ability to effectively and efficiently control sprout development from stored potato tubers is critical for maintaining quality and storability (Riggle et al., 1997). To inhibit sprout formation in potatoes, synthetically derived sprout suppressants have been applied. Chemical sprout suppressants are used commercially to prevent loss of potato processing quality that would otherwise occur due to sprouting, tuber weight loss and increased levels of reducing sugars during storage ((Kalt et al., 1999)). Sprout suppressants can be applied when the crop is growing or in storage after harvest (Sliningер et al., 2003).

2.4.2.1 Isopropyl-N (3-chlorophenyl carbamate)

Isopropyl-N (3-chlorophenyl carbamate) (CIPC) is a selective and systemic herbicide that belongs to the N-phenylcarbamate group of pesticides ((Paul et al., 2016)). It is a primary N-phenyl carbamate belonging to a group of pesticides known as carbamates which are estimated to account for 11% of the total insecticide sales globally (Smith and Bucher, 2012). It was introduced in 1951 and has been in use commercially as a sprout suppressant for over 50 years (Ezekiel, 2005; Teper-Bamnolker et al., 2010; Smith and Bucher, 2012). CIPC acts as a mitotic inhibitor by interfering with the process of spindle formation during the cell division process thereby effectively preventing new growth (Vaughn and Lehnen, 1991; Kleinkopf et al., 2003; Frazier et al., 2004; Lewis et al., 1997). Additionally, it is known to inhibit protein synthesis, RNA synthesis, activity of β-amylase along with suppression of transpiration and respiration and interfere with of oxidative phosphorylation and photosynthesis ((Vaughn and Lehnen, 1991)). CIPC is used to control weeds in growing crops and also as a sprout suppressant on harvested crops during long-term storage (Finnerty and Klingman, 1962; Sakaliene et al., 2008; Khan et al., 2012). Since its introduction, its use has gradually spread in developed and then in developing nations (Ezekiel, 2005; Ezekiel et al., 2005). It has been shown to be an effective sprout suppressant for extended storage duration of potato tubers at 8-12^{o}C with negligible or no detrimental effect on potato quality aspects (Smith and Bucher, 2012; Ezekiel et al. 2005; Mehta et al., 2010; Blenkinsop et al., 2002). Its efficacy has been reported to decrease at temperature above 15^{o}C (Sanli et al.,

2010; Ezekiel et al., 2005; Kleinkopf et al. 1997). However, effectiveness of CIPC has been demonstrated at temperature above 15 °C under traditional non-refrigerated storage systems in number of studies (Ezekiel et al. 2002; Mehta et al., 2010, 2007). Cell division is extremely important for the wound-healing period after harvest therefore CIPC must be applied after the wound-healing period is over, and before dormancy end or commencement of sprout growth (Kleinkopf et al., 2003). Being the most widely used sprout suppressant, the information of its efficacy under high storage ambient temperature experienced in most tropical countries is scarce.

2.4.2.2 1, 4-Dimethylnaphthalene

1, 4-Dimethylnaphthalene (1,4-DMN) is a naturally occurring volatile compound in potatoes; discovered in the early seventies by scientists in the United Kingdom then introduced to the US market in 1996 as a reduced risk chemical for use as a sprout inhibitor of stored potato tubers (De Weerd et al., 2010). Its mode of action is not well understood though it is thought to inhibit sprouting through hormonal action (Kleinkopf et al., 2003). Its effect is temporal and reversible with time (Beveridge et al., 1981b; Knowles et al., 2005). Meigh et al. (1973) identified and tested several compounds found in potato tuber and concluded that 1, 4-DMN and 1, 6-DMN were the most potent sprout growth suppressants in the potato tuber comparable to the effectiveness of CIPC. Beveridge et al. (1981a) examined the properties of 20 volatile substances occurring within a tuber and concluded that 1, 4-DMN was an effective sprout inhibitor sufficient for commercial use.

2.4.2.3 Peppermint oil

Peppermint (*Mentha piperita*) is an essential oil characterized by monoterpene compounds such as Menthol (40.5–48.4%), menthone (14.6–22.1 %) menthylacetate (3.8%) 1,8-cineole (6%), limonene (2%) and small amounts of pulegone, caryophyllene and pinene (Baydar and Karadogan, 2003). The mode of action of peppermint oil is still not well understood though it has been reported to work through physical damage of developing sprouts when its concentration is high enough within the headspace (Frazier et al., 2004). Vaughn and Spenser (1991) identified various monoterpenes among them 1,8-cineole, menthol, limonene and pulegone and found them to have phytotoxicity effects on tuber sprouts. However they did not discover any chemical factor particularly associated with phytotoxicity. The authors

therefore suggested that volatility of these compounds could play a vital role in their level of phytotoxicity. This natural compound has been investigated and found to have promising sprout control capacity (Kleinkopf et al., 2003). Peppermint oil has been reported to be a promising alternative to CIPC because it is environmentally friendly, low residue, effective sprout suppression, low human toxicity and low cost (Vaughn and Spencer, 1991; Frazier et al., 2004).

2.4.2.4 Paclobutrazol

Paclobutrazol (PBZ) is a plant growth regulator belonging to the triazole group; known to interfere with endogenous gibberellin synthesis through inhibition of the three steps in the oxidation of gibberellins precursor ent-kaurene to ent-kaurenoic acid in the ent-kaurene oxidation pathway (Hedden and Graebe, 1985). Plants treated with Paclobutrazol have been reported to contain low levels of gibberellins (Rademacher et al., 1987; Steffens et al., 1992). As a result of this inhibition, Paclobutrazol has been reported to inhibit cell elongation thereby retarding plant growth in a various plant species including potato (Balamani and Poovaiah, 1985). Compared with other plant growth retardants, the triazoles are required in small quantities to inhibit growth (Davis et al., 1988). Some of the effects of Paclobutrazol are reversible upon gibberellins application (Gilleyand Fletcher, 1998). PBZ has been used on fruit trees to control vegetative growth (Saran et al., 2008). Paclobutrazol has been reported to extend potato tuber dormancy as well (Harvey et al., 1991; Tekalign and Hammes, 2004; Bandara and Tanino 1995). Paclobutrazol has usually been applied as either a foliar spray or soils drench (Hunter, 1992). Knowing the effect of PBZ in field conditions; with relatively high ambient temperatures (20-30^{o}C) such as normally experienced in tropical countries like Kenya will be an important sprout management tool.

2.4.2.5 Ethylene

Ethylene is a plant hormone produced naturally in many plant organs (Arshard and Frankenberg, 2012). It is also commercially available as ethephon. Ethylene's involvement in sprout growth suppression was first reported in the 1930s, sometime after the publication of its sprout promoting properties (Bridon, 2006). Ethylene has varying effects on crops. Pre-harvest and post-harvest application of ethylene releasing agent (ethephon) has been reported to result in significant tuber dormancy extension (Suttle, 1998). Application of ethephon

during onion bulb development was reported to reduce sprouting in storage (Thomas et al., 1982) while post harvest application resulted in enhanced sprouting (Abdel-Rahman and Isenberg, 1974). In other studies, exogenous application of ethylene has resulted in contradictory reports. It has been shown to promote or delay sprouting and sprout growth depending on duration of exposure as well as the concentration (Daniels-Lake et al., 2005; Suttle, 1998; Bufler, 2009). Rylski et al. (1974) discovered that Ethylene markedly shortens the duration of rest, but it inhibits elongation of the sprouts in potatoes during extended treatment. A study by Prange et al. (1998) revealed that continuous exposure to ethylene at 4 $\mu l\ l^{-1}$ substantially suppressed tuber sprouting during long term storage, and was an effective sprout control agent. Daniels-Lake et al. (2005) confirmed that treatment with ethylene at concentration of 400, 40, and 4 $\mu L\ L^{-1}$ inhibited sprout growth as effectively as CIPC. The effect of exogenously applied ethylene is fully reversible upon removal of ethylene treatment (Rylski et al., 1974). Therefore, exogenous ethylene does not influence dormancy but can be considered as a general growth inhibitor (Suttle, 2009). Endogenous ethylene has been proposed to play a significant role in tuber dormancy regulation (Suttle, 2004). Endogenous ethylene may be involved in maintenance of bulb dormancy as suggested by the dormancy breaking effect of 1-MCP (Bufler, 2009). Ethylene can effectively control sprouting, is relatively cheap to apply, and does not leave any residue ((Prange et al., 1998)). Most of the research has focused mainly on the effect of post-harvest application of ethylene to potato tubers and little information exists on the effects of pre-harvest application of ethylene on tuber dormancy during storage.

2.5 Management of post harvest losses of ware potato through packaging

Shelf life of harvested vegetables is affected by factors such as respiration, transpiration, biological structure, ethylene production and action, compositional changes (pigments, phenolics, cell wall components, starch to sugar conversion, organics and amino acids, volatile compounds, vitamins), developmental processes and physiological breakdown (Irtwange, 2006; Kader et al., 1989). Packaging is an important aspect in food preservation. The type of packaging material used plays a significant role in determining the keeping quality of the packaged product. Ideally, packaging should protect food products from deterioration and contamination. Modified atmosphere packaging (MAP) is a common term in packaging of fresh fruits and vegetables. MAP within a package is created through

products respiration that consumes O_2 and releases CO_2 resulting in an atmosphere with low O_2 and high CO_2 over a period of time (Mattos et al., 2012). Generally, MAP reduces physiological and chemical changes of fruits and vegetables during storage (Lee and Kader, 2000). Packaging creates a modified atmosphere within the package resulting in reduced weight loss, reduced ethylene production and action, reduced respiration, delay in senescence of stored commodity, growth of decay causing microorganism is retarded thereby extending the shelf life (Kader, 2004; Beaudry, 2000; Kader et al., 1989; Gorris and Peppelenbos, 1992; González-Aguilar et al., 1999; Fallik and Aharoni, 2004). MAP has been reported to be a suitable substitute for refrigeration to prolong the storage life of fresh produce during transport and retail handling ((Kader et al., 1989; Mathooko, 2007)). The oxygen (O_2) and carbon dioxide (CO_2) must be within the optimum concentration; and the modified atmosphere must be suitable to a specific commodity for the benefits to apply (Kader and Rolle, 2004). Use of wrong packaging material may lead to quality losses of the product (Gorris and Peppelenbos, 1992; Beaudry, 2000). Exposure of potato tubers to O_2 levels below their tolerance limits and CO_2 levels above their tolerance limits can induce physiological disorders such as black heart (Kader et al., 1989). MAP can be active or passive. In active MAP, the desired gas composition of O_2 and CO_2 is introduced into the package before sealing whereas in passive MAP, a change in gas composition within the sealed package is influenced by product respiration and film permeability (Kader et al., 1989). Materials that have been previously used in packaging are glass containers, metal, aluminium foil, paperboard and plastics paper (Marsh and Bugusu, 2007). Today, plastic films are the most widely used; accounting for about 90% of all packages owing to their convenience, quality, safety of use, inexpensive, lightweight and can be recycled (Mangaraj et al., 2009). Polyethylene (low- high-density polyethylene), polyvinylchloride, and polypropylene are the main films used in packaging fruits and vegetables (Kader and Watkins, 2000). Polyethylene film packaging creates a modified atmosphere condition in addition to maintenance of high relative humidity and reduction of water loss, shrinkage and wilting; improved sanitation by reducing contamination of the products during handling; protection from surface abrasions; reduced spread of decay from one produce item to another and ease of handling (Irtwange, 2006; Kader and Watkins, 2000). However, film packaging can lead to an increase of decay due to excess humidity; initiation and intensification of physiological disorders; internal browning in potatoes and increased susceptibility to decay (Irtwange, 2006). Packaging of

respiring products in impermeable plastic films can result to O_2 depletion (less than 2%) and CO_2 accumulation that can cause anaerobic respiration of stored commodity (Aharoni et al., 2007). Modified atmosphere created by polymeric film was reported to increase the storage life of fruits and vegetables through reduction of water loss, ethylene production and respiration (Mathooko, 2003; Mathooko et al., 1993). Packaging tubers in dark plastic bags has been proposed as a way to reduce greening in retail market (Pavlista, 2001). Nearly all potato tubers in the market are packaged at some point in their life cycle. Therefore, it is important to test the effects packaging materials used have on quality changes of these potato tubers.

CHAPTER THREE: EFFECT OF SPROUT SUPPRESSANTS ON SPROUTING AND WEIGHT LOSS OF WARE POTATO TUBERS

Abstract

Potato is an important food crop in Kenya. However, its storability for long term use is limited due to high storage losses associated. Post harvest storage losses have been estimated to be 10% per month. Sprouting is the main cause of storage loses. Additionally, most of the locally grown cultivars have short dormancy thereby limiting both short-term and long-term ware potato storage. The effect of three sprout suppressants was evaluated experimentally for their sprout suppressing abilities under tropical conditions using three potato cultivars with varying dormancy length. Potato tubers were stored for up to 24 weeks in ambient storage of 23^{o}C. The compounds tested were chlorpropham (CIPC), 1, 4-dimethylnaphthalene (DMN) and peppermint oil. Generally, the treatments were effective in suppressing sprouting, sprout growth and weight loss. However, the treatments differed significantly in their efficacy. CIPC was the most effective sprout inhibitor with inhibition rates of more than 75%. Peppermint essential oil was the most effective treatment to reduce growth of emerged sprouts. Peppermint oil completely suppressed sprout growth until week 10 for cultivar Shangi and week 16 for cultivar Asante and Kenya Mpya. At the same time, sprouting was 100% in control treatment of all cultivars. DMN treatments did not prolong dormancy length in cultivar Shangi and Asante but it greatly reduced sprout growth. In cultivar Kenya Mpya, DMN treatment equaled the effectiveness of CIPC. Generally, CIPC, DMN and peppermint oil proved to be effective sprout suppressant even under tropical conditions characterized by high ambient storage temperatures.

A significant correlation was observed between weight loss and number of sprouts (r=0.828**) and length of sprouts (r=0.907**). Generally, weight loss was higher in treatments with more sprouts and long sprouts. The study indicated that lower number of sprouts per tuber and slower rate of sprout elongation limited weight loss during storage. Treatment with sprout suppressants resulted in reduced sprouting, sprout growth and weight loss. CIPC is most recommended for use due to its ability to suppress sprouting, minimize weight loss and tuber shriveling effectively.

Key words: CIPC, DMN, peppermint oil, potato (*Solanum tuberosum*), Sprout inhibitor, sprouting, sprout growth, sprout length, weight loss

3.1. Introduction

The potato processing industry requires a constant supply of good quality tubers. This leads to the need to offer appropriate quality raw materials at all times. However, seasonal production patterns, limited post harvest technologies to prevent storage losses and inadequate cold storage capacity limits availability throughout the year. Production throughout the year is unfeasible as most of the farmers rely on rainfall and there is limited or no use of irrigation. Therefore; post harvest management of the harvested crop for long term storage during non production months is inevitable. Limited post harvest storage techniques are major constraint facing the potato industry in Kenya. Post-harvest storage losses have been estimated at 10 % per month in Kenya (Janssens et al., 2013; Durr and Lorenzl, 1980). Sprouting is a major cause of quality loss in stored tubers. Sprouting leads to a rise in the rate of respiration and transpiration, remobilization of stored food reserves causing tuber shrinkage due to moisture loss, loss of tuber firmness and loss of nutritive value (Sonnewald and Sonnewald, 2014; Rezaee et al., 2011; Pinhero et al., 2009; Suttle, 2004; Teper-Bamnolker et al., 2010).

In the major potato producing areas of Kenya, potatoes are harvested during the hot months of January–March and August–September. Due to limited post harvest storage systems, scarcity of alternative markets, absence of cold storage system and lack of treatment with sprout inhibitors usually result in market oversupply; accompanied by high price reduction during the major harvesting months. Within 2-3 months later, the potato prices are inflated due to scarcity of the potatoes. Most of the farmers are not able to hold their harvested potatoes for long for price speculation due to the problem of sprouting. Postharvest losses as a result of sprouting, rotting and weight loss are particularly high under non-refrigerated storage environments with high ambient temperatures. Most of Kenyan potato varieties are reported to have a dormancy period of 1–2 months (NCPK, 2015). Therefore, sprout management has to be a consideration of both short-term and long-term storage in high ambient temperature storage conditions.

Potato sprout suppressants such as Isopropyl N-(3- chlorophenyl carbamate) (CIPC) are usually applied to suppress sprouting in storage when tubers are stored at temperatures greater than 7–8 °C (Hartmans et al., 1995 ; Kerstolt et al., 1997). CIPC is the most commonly used sprout suppressant on potatoes and has been in use for more than 50 years

(Paul et al., 2016). CIPC acts as a mitotic inhibitor by interfering with the process of spindle formation during the cell division hence effectively prevents new growth leading to sprout inhibition (Kleinkopf and Frazier, 2002).

1, 4-Dimethylnaphthalene (DMN), an isomer of dimethylnaphthalene is a naturally produced compound in potato. It has been shown to exhibit sprouting suppressing effects on potato tubers. In earlier studies, 1, 4-dimethylnaphthalene and 1, 6-dimethylnaphthalene have been shown to have suppressing ability comparable to that of CIPC (Meigh et al., 1973). Its mode of action is still not clear but it has been suggested that it acts by extending the natural period of dormancy through regulation of phytohormones (Beveridge et al., 1981b; Campbell et al., 2010; Kleinkopf et al. 2003).

Natural compounds containing monoterpenes have been investigated and found to be effective potato sprout inhibitors. The main monoterpenes in peppermint oil (PMO) are Menthol 40–45%, menthone 20–30% and lower concentration of methyl acetate, 1,8-cineole and pulegone (Gómez-Castillo et al., 2013; Maffei et al.,2001). Essential oil of peppermint has been analyzed for promising sprout inhibition capacity (Frazier et al., 2004). This oil, which is extracted from mint plants, is effective in maintaining a sprout-free condition in stored potatoes. The mode of action of these monoterpenes in sprout control is not clear but they inhibit sprouting by causing cell membrane damage mainly at the meristem tips of the sprouts (Vaughn and Spencer, 1991).

A lot of research has been done in the temperate conditions on the efficacy of sprout suppressants. However, there is limited information in the literature on the efficacy of these sprout suppressants under tropical environment such as Kenya. In addition, being a tropical country, Kenya is characterized by high ambient temperatures ranging between 20 – 40^{o}C, all the year round with a mean of 25 – 30^{o}C. This has its adverse effect on the storability of potato tubers meant for processing and for table use. This study was therefore designed to evaluate the efficacy of CIPC, DMN and peppermint oil on storage behavior of three commercial cultivars of potato grown under climatic conditions of Kenya.

3.2. MATERIALS AND METHOD

3.2.1. Plant material

Three potato cultivars (Shangi, Asante and Kenya Mpya) were used in the study. These potatoes were grown at the kabete field research station of the University of Nairobi between April- July 2013 (season 1) and between October- January 2013 (season 2). The area is sub-humid with an average temperature of 23^{o}C with a bimodal rainfall pattern. 'Shangi' has a very short dormancy (<30 days) period while 'Asante' and 'Kenya Mpya' have medium dormancy period (<60 days). Certified potato seeds were planted in 75 cm between rows with 30 cm within rows in 4 x 4 m plots. At planting, Diammonium phosphate (DAP) fertilizer was applied at the rate of 500kg ha^{-1}. Standard agronomic practices recommended for potatoes including ridging, pest control, fertilization and weeding were followed. The field experiment was laid out in a randomized complete block design with three blocks. 10 days to harvesting, the crop was dehaulmed. The potatoes were hand harvested 110 and 100 days after planting for season 1 and season 2 respectively. The tubers were transported to the laboratory about 1km away. The freshly harvested potato tubers were immediately sorted out and healthy tubers above 55mm in diameter; free of any evident disease and without any signs of sprouting were selected for the study. The potato tubers were then subjected to the treatments below and stored for 24 weeks.

3.2.2. Treatment application

i. Peppermint oil

Pure essential oil was used from peppermint (*Mentha piperita)* (Sigma-Aldrich, USA CAS-No.: 8006-90-4). Application of the essential oil treatments was based on the wick method used by Frazier et al. (2004). Twenty potato tubers were put into khaki bags then wrapped with plastic bags to prevent the mint oil from venting out. Essential oils were applied in form of vapour by putting inside the bag with the tubers a filter paper impregnated with peppermint oil. The filter paper with the essential oil was put between the khaki bag and the polyethylene bag so that no direct physical contact with the tubers occurred. The doses used in this study were 50 ppm peppermint per sample applied after every two weeks for 24

weeks. The storage bags were opened twice a week for five minutes to allow gaseous exchange for the respiring potatoes.

A control experiment was conducted in the same conditions as the peppermint oil experiments although without any treatment.

ii. Isopropyl-N-phenylcarbamate (Chloropropham) CIPC

Pure CIPC (Sigma-Aldrich, USA. CAS-No. : 101-21-3) was used. Granules containing 95% CIPC were dissolved to make a solution used to spray the tubers. Potato tubers were thinly spread on a plastic tray and CIPC was uniformly sprayed to get a dose of 22 mg kg^{-1} a.i. on tubers. After treatment, the tubes were wrapped in airtight plastic bags for 24h. 20 treated tubers were packed in khaki bags then wrapped in plastic bags. The experiment was replicated three times. The storage bags were opened twice a week for five minutes to allow gaseous exchange for the respiring potatoes.

iii. 1, 4-Dimethylnaphthalene

Dimethylnaphthalene was applied at the rate of 100 mg a.i. kg^{-1} of fresh tuber weight as a liquid fog. 1, 4 dimethylnaphthalene analytical standard purchased from commercial suppliers (Sigma-Aldrich, USA CAS Number 571-58-4) was used.

After treatment, the tubers were wrapped in airtight plastic bags for 24h. 20 treated tubers were packed in khaki bags then wrapped in low density plastic bags. The storage bags were opened twice a week for five minutes to allow gaseous exchange for the respiring potatoes. The control experiment was conducted in the same manner as the CIPC and DMN treatment but it was sprayed with distilled water only. The samples were then randomly distributed in the shelves in the laboratory in a 3 x 4 factorial combination of treatments.

3.2.3. Data collection

Sprout development was visually observed weekly to determine the duration of the sprout inhibition effect of the treatments. When over 80% of the tubers had visible sprouts (≥ 3 mm long) in a sample, it was considered as end of dormancy. This was determined by evaluating samples of 20 tubers for sprouting %, sprout length, sprout thickness and number of sprouts per tuber. Measurements on the number of tubers with sprouts in each treatment and control were taken before the treatment and weekly thereafter for 24 weeks. Tubers with at least one

sprout equal to or greater than 3 mm long were considered as sprouted. Data were collected as follows:

i. Sprouting percentage

Sprouting percentage was calculated as the percentage of the number of sprouted tubers in the sample then averaged on per sample basis. This was done weekly.

ii. Sprout length

It was determined by measuring the length of the longest sprout in every sprouted tuber per sample. Measurements were done from the base of the sprout to the tip and data recorded in mm. The data was averaged on per tuber basis

iii. Number of sprouts per tuber

The number of sprouts per tuber were evaluated by counting all the sprouts (≥3mm) in every sprouted tuber per sample and the average was calculated on per tuber basis.

iv. Weight loss

Weight loss was calculated as the change between the initial weight at the beginning of the experiment and the final weight measurements at the end of 24 weeks of storage. The change in weight was expressed as a percentage of the initial weight.

3.2.4. Data analysis

Analysis of variance was performed for each variable using Genstat statistical program (14^{th} Edition, VSN, UK, 2010). The means were compared using Tukey's significant difference test at 5% level of significance. The treatments were arranged in a randomized complete block design with three replications per treatment

3.3 RESULTS

3.3.1 Sprouting %

There was significant ($P \leq 0.05$) interaction between treatment, cultivar and storage duration. Initial sprouting of previously dormant tubers of control treatment started about week 3 for cultivar Shangi and week 9 for cultivars Asante and Kenya Mpya. Dormancy end followed at week four for cultivar Shangi and week 10 for cultivar Asante and Kenya Mpya. All the tubers in the control treatments had 100% sprouting with numerous sprouts by the end of 24 weeks storage duration (Fig. 3.2). The rate of sprouting between cultivar Asante and Kenya Mpya control treatments was similar throughout the experiment.

Low tuber sprouting %, number of sprouts per tuber and sprout length due to application of the sprout suppressants compared to the untreated control was observed (Fig 3.1). CIPC presented the most efficient sprout inhibitory effect. CIPC treatment at the concentration of 22 mg kg^{-1} reduced sprouting to 23.33% and 16.67% and 10% for cultivars Shangi, Asante and Kenya Mpya tubers, respectively 24 weeks after treatment in storage. Sprouting was not observed in any tuber; 18 weeks after CIPC treatment. Sprouting was first observed at week 20 irrespective of the cultivar and there was no significant difference among the cultivars observed in sprouting % between weeks 20-22. However, at week 24, cultivar Shangi recorded significantly higher sprouting % than cultivar Kenya Mpya. Generally, sprouting increased with increased storage time. Tubers of all cultivars treated with CIPC appeared firm while the untreated control tubers had a shriveled appearance (Fig. 3.2).

The sprout suppression effect of DMN treatment varied significantly among cultivars (Fig. 3.1). In this study better results were obtained with cultivar Kenya Mpya tubers than cultivar Shangi and Asante tubers. In fact, there was no statistically significant difference in % sprouting between cultivar Kenya Mpya tubers receiving CIPC treatment and those receiving DMN treatment. DMN treatments maintained complete sprout inhibition for 16 weeks after treatment for cultivar Kenya Mpya. However, in cultivar Shangi and Asante, DMN had a moderate inhibitory effect with relatively high sprouting levels and the treated tubers began sprouting at the same time with their respective control treatment. Although the control and DMN treatment began sprouting at the same time, DMN treatment had significantly lower rates of sprouting compared to the control treatment. At the end of 24 weeks storage, sprouting % were 76.67% and 63.33% for cultivar Shangi and Asante, respectively whereas

the control treatment had 100% sprouting at the same point in time. Figure 3.3 shows tuber appearance for the DMN treatments after 24 weeks of storage for cultivar Asante and Kenya Mpya.

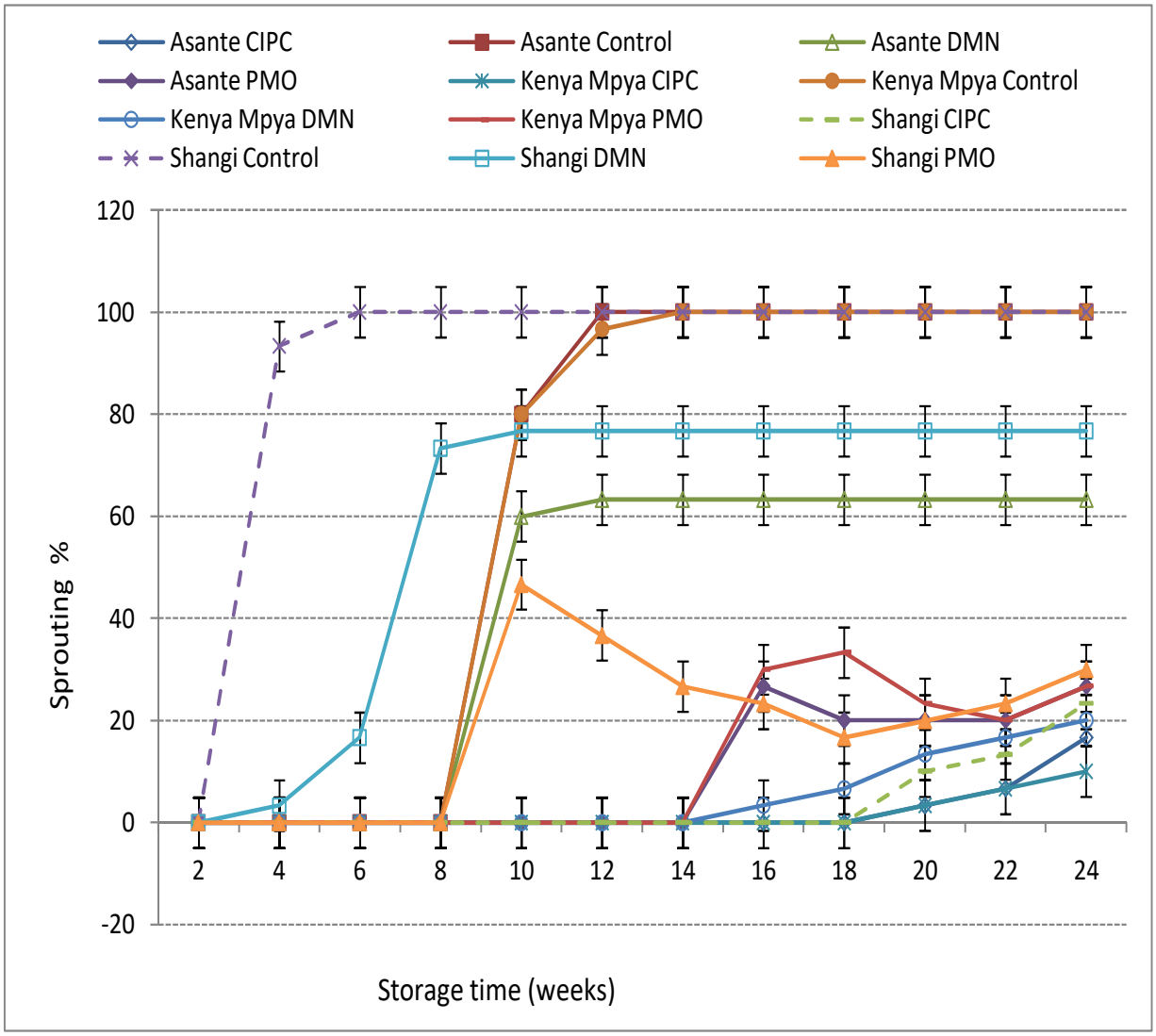


Figure 3. 1: Sprouting (%) for cultivars Shangi, Asante and Kenya Mpya potato tubers treated with peppermint oil (PMO), CIPC, 1,4-DMN

Figure 3.2: Sprouting and tuber shriveling in control treatments and sprout suppression in CIPC spray treatments (22 mg kg^{-1} fresh tuber weight) after 24 weeks in storage.

Legend: CIPC- Isopropyl N-(3- chlorophenyl carbamate)

Legend: CIPC- Isopropyl N-(3- chlorophenyl carbamate)

DMN-Dimethylenaphthalene

Figure 3.3: Appearance of tubers at week 24 for the different treatments

Peppermint oil was an effective sprout suppressant leading to a 30%, 26.67% and 26.67% of sprouting by the end of storage duration for cultivars Shangi, Asante and Kenya Mpya respectively (Fig. 3.1). Treated tubers only began sprouting at week 10 for cultivar Shangi and week 16 for cultivar Asante and Kenya Mpya. Although cultivar Shangi tubers receiving PMO treatment began sprouting earlier than cultivar Asante and Kenya Mpya, at the end of the experiment, sprouting % were close to each other and no significant difference was observed among the cultivars. However, best result were obtained from cultivar Asante and Kenya Mpya treated tubers (26.67%) followed by cultivar Shangi (30%). Generally, PMO treatment was not as effective as CIPC treatment but it was more effective than DMN treatment. At week 20, sprouting was complete on control treatment (100%) whereas at the same time sprouting was <25% on PMO treatment, and by the end 24 weeks in storage ≤30% sprouting was recorded. The number of sprouted tubers was initially high. However, due to the necrosis of the emerging sprouts on tubers as a result of retreatment, the numbers of sprouted tubers decreased in the following weeks. When the concentration went down, tubers would resume normal sprouting. Generally, cultivar Asante tubers had lower levels of sprouting than Shangi tubers irrespective of the treatment. All the tubers receiving DMN, CIPC and PMO treatment maintained tuber firmness as compared to the control (Fig. 3.2 and 3.3).

3.3.4 Number of sprouts per tuber

The number of sprouts per tuber was significantly ($P<0.05$) influenced by the interaction effect of the treatment, cultivar and storage period. Generally, the control treatment gave significantly higher sprouts number per tuber. Differences among cultivars were statistically significant throughout the experimental period. Sprout growth was observed at the beginning of the experiment for control treatments and consequently the control treatment maintained the highest number of sprouts per tuber compared to DMN, CIPC and peppermint oil throughout the experimental period (Table 3.1). By the end of the experiment, control treatment recorded 15.2, 7.9 and 15.1 sprouts per tuber for cultivars Shangi, Asante and Kenya Mpya, respectively. Sprouts number increased with increasing storage time for the control and CIPC treatments. For peppermint oil treatment, the number of sprouts increased and reduced periodically. This occurred after retreatment with peppermint oil caused necrosis of emerged sprouts that withered and easily fell off during handling thereby reducing the

number of sprouts. When the concentration of the mint oils went down, more sprouts emerged.

Table 3. 1: Effect of sprout suppressants on the number of sprouts per tuber of 3 cultivars in Kenya

		Number of sprouts per tuber											
		Duration of storage (weeks)											
Treatment	**Cultivar**	2	4	6	8	10	12	14	16	18	20	22	24
Control	Asante	0	0	0	0	1.3	1.833	3.033	4.2	5.633	6.333	7.933	7.933
CIPC		0	0	0	0	0	0	0	0	0	0.03	0.13	0.2
DMN		0	0	0	0	1.833	1.867	3.333	4.4	4.967	4.867	4.133	4
PMO		0	0	0	0	0	0	0	0.133	0.8	0.667	0.633	0.8
Control	Kenya Mpya	0	0	0	0	1	3.267	5.167	7.6	8.667	12.333	13.533	15.067
CIPC		0	0	0	0	0	0	0	0	0	0.1	0.133	0.2
DMN		0	0	0	0	0	0	0	0.033	0.133	0.267	0.433	0.567
PMO		0	0	0	0	0	0	0	2.6	2.2	1.4	0.6	1.5
Control	Shangi	0	1.8	6.767	13.133	13.433	13.7	13.9	14.067	14.3	14.567	15.033	15.167
CIPC		0	0	0	0	0	0	0	0	0	0.233	0.267	0.3
DMN		0	0.067	0.4	3.2	3.367	3.833	4.833	4.6	4.233	3.6	3.4	3
PMO		0	0	0	0	2.833	2	1.1	0.8	0.9	1	1.3	1
LSD (5%)		ns	0.2787	0.5494	0.5154	0.6627	0.6091	0.7730	0.7009	0.5935	0.9148	0.6931	0.7695

LSD ($p \leq 0.05$): C 0.0791,LSD ($p \leq 0.05$): T 0.0913, LSD ($p \leq 0.05$): SD 0.1646, LSD ($p \leq 0.05$): C X T 0.1581, LSD ($p \leq 0.05$): C X SD 0.2851,

LSD ($p \leq 0.05$): T X SD 0.3292, LSD ($p \leq 0.05$): C X T X SD 0.5702

Legend: PMO - Peppermint oil, DMN- Dimethylnaphthalene, C= Cultivar, T= treatment, SD= storage duration, ns= storage duration

In DMN treatment, the number of sprouts increased initially then started to decline towards the end of the experiment in cultivar Asante and Shangi tubers. This was as a result of necrotic sprouts falling off during handling. CIPC treatments produced the lowest number of sprouts per tuber and at the end of the experiment all treatments had less than 0.3 sprouts per tuber (Table 3.1).

Sprouting on tubers was delayed until week 20 and as a result, the lowest number of sprouts per tuber was recorded for the CIPC treatments. Statistically significant differences among the cultivars were not observed.

For the peppermint oil treatments, sprout number varied between 0.8-1.5 sprouts per tuber. The lowest number of sprouts on tubers was found in cultivar Asante while the highest number of sprouts was in cultivar Kenya Mpya at the end of the experiment. The number of sprouts was initially high (2.8 and 2.6 for cultivars Shangi and Kenya Mpya respectively) earlier in the experiment but it was reduced due to necrosis of emerged sprouts resulting from retreatment with peppermint oil.

Sprouting between the control and DMN treatments began at the same time for cultivars Shangi and Asante. However, DMN treatment maintained lower number of sprouts throughout the experimental duration (Table 3.1). 24 weeks after treatment, DMN treated tubers had 3, 4 and 0.6 for cultivars Shangi, Asante and Kenya Mpya respectively. At the same time, the control recorded 15.2, 7.9 and 15.1 sprouts per tuber for cultivars Shangi, Asante and Kenya Mpya respectively. The lower number of sprouts per tuber observed in cultivar Kenya Mpya resulted from late sprouting. There was no significant difference in number of sprouts per tuber between CIPC and DMN treatment for cultivar Kenya Mpya. As storage time progressed, the number of sprouts for DMN treatment reduced for cultivar Shangi and Asante. This was as a result of falling off of necrotic sprouts during handling.

4.3.5 Longest sprout length

Sprout length was significantly ($P \leq 0.05$) influenced by the interaction effect of treatment, cultivar and storage period. Generally, the control treatment in all the cultivars maintained the highest sprout length up to the end of the experiment (Fig 3.4). Sprout length differed significantly with cultivar throughout the 24 weeks of storage. However, at week 22, there was no significant difference in sprout length among the cultivars (Fig 3.4). Sprout length

was not consistent with storage time among the cultivars and no particular cultivar dominated. However, at the end of storage, cultivar Kenya Mpya recorded the highest sprout length of 23.14mm whereas cultivars Shangi and Asante recorded sprout length of 20mm and 18.24mm respectively. Cultivar Kenya Mpya and Asante have similar dormancy length but their sprouting characteristics differ significantly. Sprout length in the control treatment was found to increase with storage time although it was frequently arrested by apical sprout tip necrosis.

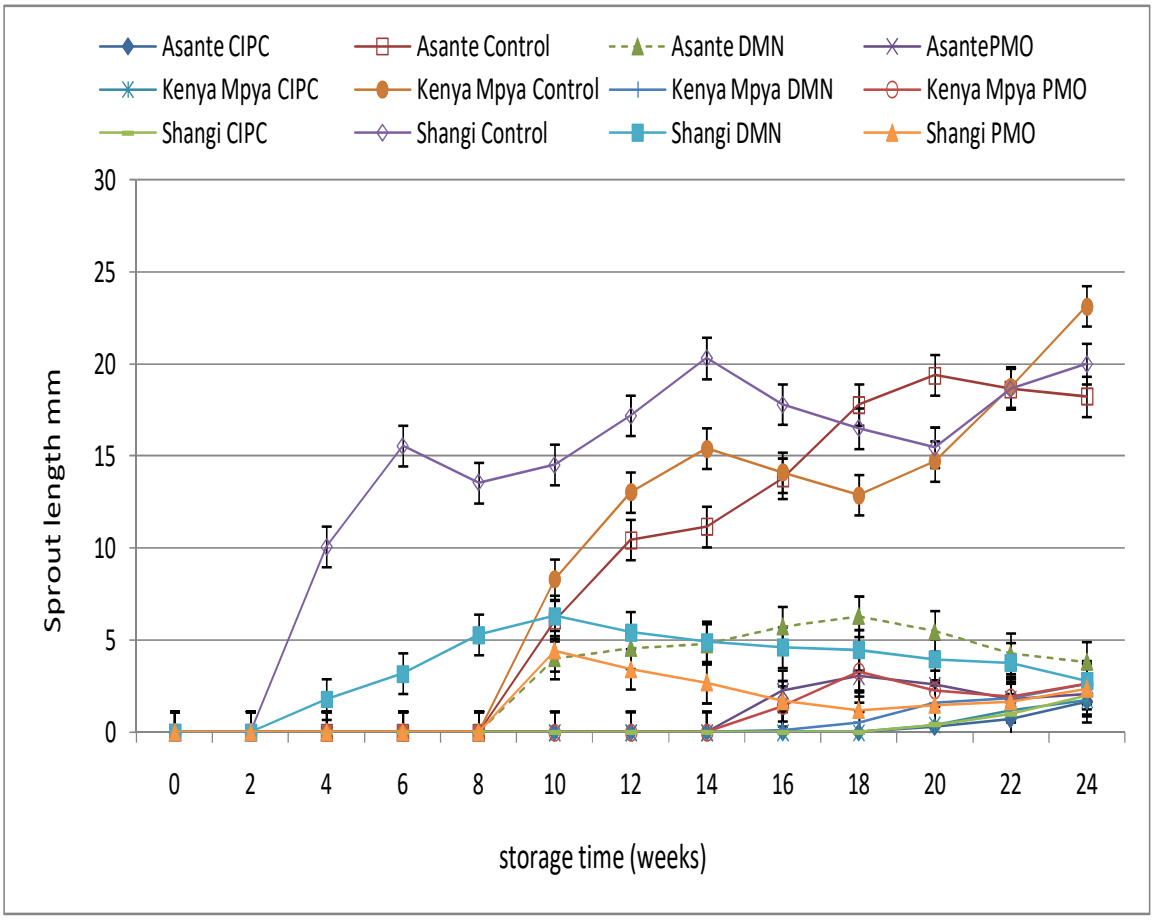


Figure 3.4: Effect of sprout suppressants on sprout length of tubers from three potato cultivars

All the treatment effectively suppressed sprout growth compared to the control (Fig 3.4). CIPC presented the most effective sprout growth suppressant that resulted in sprout length of 2mm, 1.67mm and 1.77mm for cultivars Shangi, Asante and Kenya Mpya respectively 24

weeks after treatment. Sprout emergence was delayed until week 20 for CIPC treated tubers in all the cultivars. As a result, the lowest sprout length was recorded for this treatment. Sprout length increased with storage time up to the end of experiment.

DMN treatment effectively reduced increase in sprout length. A single application of DMN at 100 mg kg^{-1} maintained a sprout length of <4 mm after 24 weeks in storage. Sprouts on the untreated tubers averaged 20mm, 18.24mm and 23.15mm in length for cultivars Shangi, Asante and Kenya Mpya, respectively at this same point. Despite sprouting at the same time, there was a substantial decrease in tuber sprout length due to applications of DMN compared to the untreated control (Fig 3.4). In cultivar Kenya Mpya, DMN treatment was equal to the effectiveness of one CIPC application in reducing sprout growth. Although sprout emergence was earlier for DMN treatment (week 16) compared to CIPC treatment (week 20), no significant difference was observed at any time for 24 weeks for cultivar Kenya Mpya. DMN treatment caused sprout tip necrosis thereby reducing the sprout length and limiting sprout elongation. Tuber sprout length of this magnitude after 24 weeks in storage would not adversely affect the processing quality nor for the fresh market industry.

Peppermint oil treatment was an effective sprout growth suppressant. It was not as effective as CIPC treatment, but it was more effective than DMN treatment in reducing sprout elongation. At the end of experiment, sprout length was 2.37mm, 2.45mm and 2.64 for cultivars Shangi, Asante and Kenya Mpya, respectively. Sprout elongation was greatly reduced by the effect resulting from Peppermint oil retreatment. It was initially high (4.43mm, 3.04mm and 3.21mm cultivars Shangi, Asante and Kenya Mpya, respectively) then reduced due to sprout tip necrosis irrespective of cultivar. After all the cultivars had began sprouting at week 16, statistical significant differences in sprout length was not observed.

4.3.7 Weight loss

Weight loss was significantly ($P \leq 0.05$) influenced by the interaction effect between the treatments and the cultivars. Total weight losses were highest in control treatment in all the cultivars. Weight loss in the three cultivars not receiving the treatment did not differ significantly (Fig. 3.5). However, though not statistically significant, cultivar Kenya Mpya recorded the highest weight loss (14.72%) compared to Shangi (13.94%) and Asante (12.5%). Generally, there was a significant decrease in weight loss attributable to the treatments but

the best results were recorded in CIPC treatment compared to DMN and PMO treatments. There was significantly high weight loss of CIPC treated tubers of cultivar Shangi than cultivar Kenya Mpya and Asante (Fig. 3.5). The weight loss was less than 10% in all the treated tubers. It was minimum in CIPC treatment (3.79%, 5.58% and 6.57% for cultivar Kenya Mpya, Asante and Shangi, respectively) and maximum in DMN treatment (5.07%, 8.65% and 9.21% for cultivar Kenya Mpya, Asante and Shangi respectively). Weight loss in PMO treatment was intermediate with 6.25%, 6.05% and 8.08% for cultivar Kenya Mpya, Asante and Shangi respectively. Weight loss in DMN treated tubers differed significantly with cultivar. It was minimum in cultivar Kenya Mpya and maximum in cultivar Shangi (Fig 3.5).

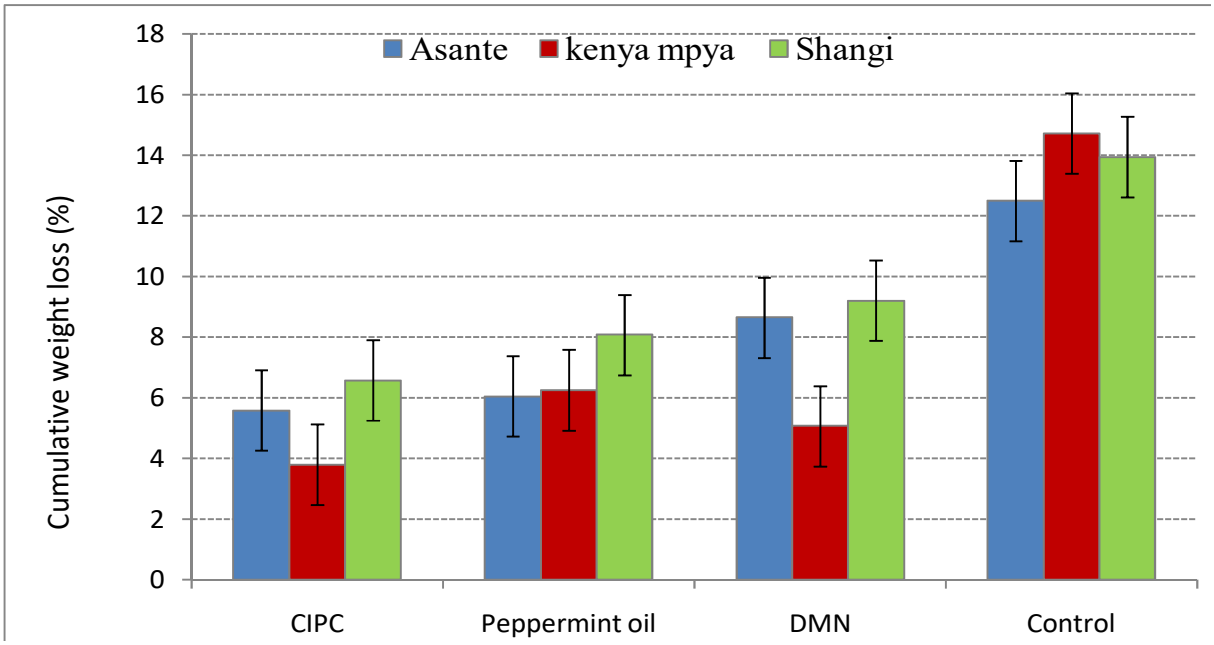


Figure 3. 5: Cumulative weight loss (%) in potato tubers of Asante, Kenya mpya and Shangi cultivars treated with peppermint oil, DMN, CIPC and their respective control at the end of the storage period.

There were significant correlations ($P<0.01$) between weight loss and sprout growth (Table 3.2). Weight loss had strong positive correlation with sprout length ($r=0.907^{**}$) and the number of sprouts ($r=0.828^{**}$). Tubers with long sprout lengths lost more weight than tubers with shorter sprouts. In addition, tubers with more sprouts lost more weight than tubers with fewer sprouts.

Table 3. 2: Correlation matrix between weight loss, sprout length and sprouts number

	weight loss	Sprout length	Sprouts number
weight loss	1		
Sprout length	0.907**	1	
Sprouts number	0.828**	0.945**	1

** Correlation coefficient is significant at 0.01 probability level

3.4 DISCUSSION

The results of this study on sprouting and sprout growth evidently showed that significant sprout inhibition can be achieved for 24 weeks under high ambient storage temperatures (23°C) with a single application of CIPC at a dose of 22 mg kg^{-1}. This is in agreement with the reports of earlier workers using CIPC. Mehta et al. (2010) reported over 95% sprout inhibition after 105 days in storage when tubers were treated with CIPC at the concentration of 20 and 30 mg kg^{-1} and stored at 17– 33 °C. Tuber sprouting increased with increased storage time suggesting a decrease in CIPC efficacy over time. This could have been as a result of decreasing CIPC residue levels within the tuber beyond the level necessary for complete sprout inhibition with time. Storage time has a substantial effect on the CIPC residue present in the potato tuber. Residue level of CIPC decreases with the duration of storage (Mondy et al., 1992; Mehta et al., 2010; Sakaliene et al., 2008). Lewis et al. (1997) reported an initial residue level of f 5.47 mg kg^{-1} that reduced to 0.76 mg kg^{-1} after 202 days in storage. The authors attributed the decrease in CIPC residue over time to microbial breakdown. In this study, sprout growth in treated tubers remained remarkably suppressed. The respiration rate of tubers has been reported to reduce when tubers are treated with sprout control agents and it is shown to be positively correlated with sprout growth (Mehta, 2004).

DMN also proved to be an effective sprouting and sprout growth suppressant. A single application of DMN at the rate of 100 mg kg^{-1} maintained a sprout length of <4 mm at the end of 24 weeks in storage while sprouts on the untreated tubers averaged 20mm, 18.24mm and 23.15mm in length for cultivars Shangi, Asante and Kenya Mpya respectively. It did not prevent dormancy break in cultivars Shangi and Asante but it suppressed sprout growth effectively. These results are similar to those reported previously where DMN applied at 100, 200, and 300 mg kg^{-1} resulted in sprout length of <2 cm compared to that of untreated tubers

(12.3cm) after 194 days in storage (Lewis et al, 1997). Knowles et al. (2005) treated seed of three different cultivars and found that 1, 4-DMN-treated tubers of all cultivars maintained a sprout length of <5 mm for 200 days in storage though the treatment was repeated three times during that time. Variability of sprout suppression with the DMN treatments among the cultivars may have been due to genetic differences. De Weerd et al. (2010) tested DMN critical residue levels necessary for suppressing sprout development on three cultivars 'R. Norkotah', 'R. Burbank' and 'Shepody'. In order to maintain sprout control, tuber residues were 2.7 ppm for cultivar 'R. Norkotah', 1.6 ppm for cultivar 'Shepody' and 1.4 ppm for cultivar 'R. Burbank'. This is an indication that different cultivars require different tuber residue levels to suppress sprouting in storage.

Knowles et al. (2005) reported that DMN treated tubers contained higher residue of DMN than the untreated tubers. This could explain why despite sprouting at the same time with the control treatment, DMN treated tubers had lower sprouting rate and had reduced sprout growth. Cultivar Kenya Mpya tubers treated with DMN started sprouting towards the end of the experiment and the number of sprouted tubers increased with time. DMN residue levels within tubers have been reported to decrease with increasing storage time. This is attributable to reducing residue levels within the tuber necessary to inhibit sprouting. Decreasing residue levels with storage time has been reported (Lewis et al., 1997). 1,4-DMN tuber residue resulting after an application is determined by storage period, application method and ventilation (Weerd et al., 2010; Lewis et al., 1997). Observations of DMN treated tubers from all the cultivars revealed that developing sprouts tips turned black, necrotic after some time in storage. Similar observations were made after a second treatment with DMN (Lewis et al., 1997).

This study found that peppermint oil (PMO) treatments effectively suppressed sprouting and elongation of emerging sprouts in all the cultivars. The treatment did not prolong the natural rest period but destroyed emerging sprouts by causing sprouts necrosis resulting in reduced sprouting and sprout growth. This may be related to the phytotoxicity of some of the chemical components present in PMO, like limonene, menthol, 1,8-Cineole and Pulegone, which has been reported to cause tissue necrosis in potato sprouts (Vaughn and Spencer,1991). Furthermore, pulegone has been demonstrated to inhibit mitochondrial respiration (Mucciarelli et al., 2001) which could be an important mechanism of action

through which the monoterpenes control the growth of sprouts. The sprout suppressing abilities of PMO has been reported previously (Kleinkopf and Frazier, 2002). Gómez-Castillo et al. (2013) reported 5-14% sprouting of two cultivars tubers treated with PMO at the end of 70 days in storage while the control treatment recorded 100% sprouting. In this study, it was found that when the concentration declined, sprouting increased. Its effectiveness has been reported to be influenced by the concentration on the head space (Frazier et al., 2004; Rentzsch et al., 2012). Since peppermint oil does not work by prolonging natural rest period, this could explain why cultivar Shangi recorded early sprouting than cultivar Asante and Kenya Mpya. In addition, cultivars Asante and Kenya Mpya have similar dormancy length and when treated with peppermint oil, sprout emergence was recorded at the same storage time.

Weight loss of ware potato tubers in storage is an important quality attribute that affects their use. It results mainly from processes like sprouting, evaporation and respiration but evaporation is the main contributing factor in weight loss (Mehta et al., 2010). Evaporative loss it is increased by sprout development (Gautam et al., 2013). Weight loss showed a significant positive correlation with number of sprouts ($r=0.828^{**}$, n=36) and sprout length ($r=0.907^{**}$, n=36). Pande et al. (2007) reported similar findings while evaluating 37 potato cultivars not treated with sprout suppressants. Similarly, the differences in weight loss of CIPC, DMN, Peppermint oil and control treatment among the three cultivars during storage could be attributed to differences in their sprouting characteristics. Application of sprout suppressants resulted in reduced sprouting and sprout growth leading to a decrease in weight loss. The higher weight losses in the untreated tubers were probably due to their high rate of sprouting, high number of sprouts and high sprout growth. Higher evaporative losses occur through the epidermis of the sprouts because it is much more permeable to water vapor than tuber surface (Mani et al., 2014; Gautam et al., 2013). In addition, Sprouts have a higher surface area with faster metabolic activities which further increases moisture loss from the potato tubers. It has been reported that the epidermis of sprouts is 100 times more permeable to water loss than the tuber periderm (Benkeblia et al., 2008). Sprouting and continuous sprout growth has been reported to increase the rate of respiration and evaporation consequently increasing weight loss of stored tubers (Schippers, 1977; Benkeblia et al., 2008; Paul et al., 2016). Weight loss resulting from respiration contribute 3–9% to total losses at

storage temperature of 14-30ºC and are reported to reduce when tubers are treated with sprout inhibitors (Mehta, 2004).

CIPC performed better than other treatments for reduction of weight loss percentage. The minimum weight loss observed in tubers treated with CIPC as compared to untreated control tubers agrees with earlier findings (Mehta et al. , 2013; Mehta, 2005; Gautam et al., 2013). With CIPC treatment, cultivar Kenya Mpya lost significantly lower weight than Asante and Shangi tubers. The variations observed among cultivars in relation to weight loss could be attributed to their periderm characteristics and their sprouting behavior (Mehta et al., 2010). Neither treatment in all the cultivars lost more than 9.3% in weight during storage and therefore they are suitable for table or processing. The acceptable weight loss in potato tubers is 10% and when weight losses exceed this level, tubers become increasingly flaccid affecting their acceptability for table consumption due to their shriveled appearance (Ezekiel, 2005). In addition, the peeling losses increasing with increased weight loss affects the processing quality of potatoes (Mehta et al., 2010). Potato tubers treated with sprout suppressants lost less than 10% of their fresh weight and therefore they did not suffer sufficient moisture loss to affect their physical appearance, and consequently, the tubers could be sold for prices comparable to that of freshly harvested tubers.

4.5 CONCLUSION

In this study, CIPC treated potato tubers showed long-term storage of 24 weeks with a single spray application of CIPC at a concentration of 22 mg kg^{-1} by inhibiting shriveling, sprouting, sprout growth, weight loss and other storage losses. Cultivars differed with response to DMN treatment. When applied to cultivar Kenya Mpya tubers, it may be a superior ware potato sprout suppressant equal to CIPC. However when applied to cultivars Shangi and Asante tubers, it has the potential to provide adequate sprout growth suppression for a short duration. Peppermint oil is also able to suppress sprout development for duration of 16 weeks. The use of peppermint leaves rather than the commercial peppermint oil could be an alternative way to prevent sprouting since it is cheap, locally available and environmentally friendly. CIPC, DMN and peppermint oil proved to be effective sprout suppressant even under tropical conditions of Kenya characterized by high ambient temperatures.

CHAPTER FOUR: EFFECTS OF STORAGE TEMPERATURE ON THE EFFICACY OF POTATO SPROUT SUPPRESSANTS

Abstract

The efficacy of sprout suppressants; Chlorpropham (CIPC), 1, 4-Dimethylnaphthalene (DMN) and peppermint oil (PMO) on sprouting, sprout length and the number of sprouts per potato tuber were investigated under two different storage temperatures; reduced temperature of (10±2^{o}C) and ambient temperature (23±2^{o}C). Tubers from three cultivars with varying dormancy length were used. Data on sprouting, number of sprouts and sprout length was recorded and analysed. CIPC, DMN and peppermint oil were effective in suppressing sprouting and sprout growth in both storage conditions but the best results were obtained when treated tubers were stored at reduced temperature. The rest period decreased linearly with storage time in all the cultivars at both temperatures but it was more rapid at ambient than cold store. The most effective treatment to reduce sprouting and sprout growth was CIPC at both storage temperatures. At cold store, the effectiveness of DMN treatment was equal to that of CIPC in cultivar Kenya Mpya in inhibiting sprouting resulting in 100% inhibition. Moreover, sprout growth was completely suppressed and the tubers remained at 'peeping' stage up to the end of study. In addition, DMN was more effective to suppress sprouting and sprout growth at cold store and sprouting was completely suppressed for 4-6 weeks after onset of sprouting in control treatments for cultivars Shangi and Asante. The lowest number of sprouts per tuber was observed for CIPC and peppermint oil treatments in cultivars Shangi and Asante while in cultivar Kenya Mpya CIPC and DMN gave the lowest number of sprouts per tuber at ambient store. Peppermint oil treatments were the most effective treatments for reducing sprout elongation of emerged sprouts in all the cultivars at both storage temperatures. Peppermint oil suppressed sprout growth until week 10-16 and week 16-20 at ambient and cold store respectively in all cultivars. DMN treatments also effectively reduced sprout elongation by inducing sprout tip necrosis. Dormancy end was delayed for 4 weeks for cultivar Asante and 6 weeks for cultivar Shangi and Kenya Mpya control when the temperature was lowered from 23±2^{o}C to 10±2^{o}C. Based on the results of this study, it is concluded that the efficiency of CIPC, 1, 4-dimethylnaphthalene and peppermint oil increases as storage temperature decreases.

Key words: CIPC, 1, 4-dimethylnaphthalene (DMN), Peppermint oil, storage temperature, sprout suppressants, potato *Solanum tuberosum,* dormancy

4.1 Introduction

The sprouting of ware potato tubers during storage results in notably large losses in the total marketable tubers. Often, the management of potato sprouting is storage at low temperature or the application of sprout suppressant especially in the developed world. Low temperature storage is oftentimes used to prolong the storage time by extending the natural dormancy through an enforced dormancy (Wiltshire and Cobb, 1996). Storage temperature of 2-4ºC is ideal for long term potato storage since no sprouting occurs at this temperature (Paul et al., 2016). However, this low temperature is unsuitable for storage of ware potatoes meant for either fresh consumption or processing. This is because, such low temperature storage results in accumulation of reducing sugars (glucose and fructose) and potato tubers become sweet in taste (Sonnewald, 2001). To avoid this cold-induced sweetening of tubers, storage at 8–12 °C is the most appropriate. Burton (1989) reported that at temperature range of 8–12 °C respiration rate of potato tubers is minimum, allowing minimum accumulation of reducing sugars in the stored tubers. However, this storage temperature is favorable for sprouting and sprout growth hence treatment with sprout inhibitors becomes essential for successful long term storage. Generally, without treatment with sprout suppressants, the rate of sprouting increases with temperature and at temperature range of 3–20°C, dormancy length is inversely proportional to temperature (Wiltshire and Cobb, 1996).

Chlorpropham (CIPC), 1, 4-Dimethylnaphathalene (DMN) and peppermint oil (PMO) have been shown to be effective in controlling sprouting of stored ware potato tubers (Kleinkopf et al., 2003; Gómez-Castillo et al., 2013). However, there are few reports available in the literature on the efficacy of these sprout suppressants in different storage temperatures. This study was therefore designed to assess the efficacy of CIPC, DMN and peppermint oil treatments when tubers were stored under ambient conditions (23±2ºC) and low temperature conditions (10±2ºC) on sprouting potential and sprout growth.

4.2. MATERIALS AND METHODS

4.2.1. Plant material

Three potato cultivars with varying dormancy viz Shangi (short dormancy), Asante and Kenya Mpya (medium dormancy cultivars) were used in the study. These potatoes were grown at the Kabete field station of the University of Nairobi between April- July 2013

(season 1) and between October- January 2013 (season 2). Standard agronomic practices recommended for potatoes including ridging, pest control, fertilization and weeding were followed. Freshly harvested potato tubers free of any evident disease and without any signs of sprouting were selected and cured for 14 days under the prevailing ambient conditions before applying the treatments.

4.2.2. Treatment application

Peppermint oil

Pure essential oil was used from peppermint (*Mentha piperita*) from Sigma-Aldrich, USA CAS-No. : 8006-90-4. Application of the essential oil treatments was based on the wick method used by Frazier et al. (2004). Twenty potato tubers of uniform size were put into khaki bags then wrapped with plastic bags to prevent the mint oil from venting out. Essential oils were applied in form of vapour by putting inside the bag with the tubers a filter paper impregnated with peppermint oil. The filter paper with the essential oil was put between the khaki bag and the polyethylene bag so that no direct physical contact with the tubers occurred. The doses used in this study were 50 ppm peppermint oil per sample applied at two weeks interval. A control experiment was conducted in the same conditions as the peppermint oil experiments although without any treatment. The storage bags were opened weekly for five minutes to allow gaseous exchange for the respiring potatoes.

Chlorpropham (CIPC)

Potatoes were thinly spread on a plastic tray and CIPC (Granules containing 95% CIPC from Sigma-Aldrich, USA. CAS-No. : 101-21-3) were dissolved and uniformly sprayed to get a dosage of 22 mg kg^{-1} a.i. on tubers. After treatment, the tubes were wrapped in airtight plastic bags for 24 hours. 20 treated tubers were packed in khaki bags then wrapped in plastic bags. The experiment was replicated three times. The control experiment was conducted in the same manner as the CIPC treatment but it was sprayed with distilled water only. The storage bags were opened weekly for five minutes to allow gaseous exchange for the respiring potatoes.

1, 4-Dimethylnaphthalene

Dimethylnaphthalene was applied at the rate of 100 mg a.i. kg^{-1} of fresh tuber weight as a liquid fog. 1, 4-dimethylnaphthalene analytical standard purchased from commercial suppliers Sigma-Aldrich, USA CAS Number 571-58-4 was used. The control experiment was sprayed with distilled water only. After treatment, the tubes were wrapped in airtight plastic bags for 24 hours. 20 treated tubers were packed in khaki bags then wrapped in plastic bags. The storage bags were opened weekly for five minutes to allow gaseous exchange for the respiring potatoes.

4.2.3 Storage conditions

After treatment, potato tubers of the three cultivars were subjected to two temperature regimes, 10±2^{o}C and 23±2^{o}C. The 4 x 3 x 2 factorial combinations of treatments were laid out in randomized complete block design and replicated three times.

4.2.4. Data collection

Sprout development was visually observed weekly to determine the duration of the sprout inhibition effect of the treatments. Dormancy was considered to have ended when over 80% of the tubers in a sample had sprouts ≥ 3 mm long ((Shibairo et al., 2006)). This was determined by evaluating samples of 20 tubers for sprouting %, sprout length and number of sprouts per tuber. Measurements on the number of tubers with sprouts in each treatment and control were taken before the treatment and weekly thereafter for 24 weeks. Tubers with at least one sprout ≥3 mm were considered as sprouted. Data were collected as follows:

i. Sprouting percentage

Sprouting percentage was calculated as the percentage of the number of sprouted tubers in the sample then averaged on per sample basis.

ii. Sprout length

It was determined by measuring the length of the longest sprout in every sprouted tuber per sample. Measurements were done from the base of the sprout to the tip and data recorded in mm. The data was averaged on per tuber basis

iii. Number of sprouts per tuber

The number of sprouts per tuber were evaluated by counting all the sprouts (≥3mm) in every sprouted tuber per sample and the average was calculated on per tuber basis.

4.2.4. Statistical analysis

Analysis of variance was performed for each variable using Genstat statistical program (14th Edition, VSN, UK, 2010). The means were compared using Tukey's significant difference test at 5% level of significance.

4.3. RESULTS

4.3.1. Sprouting

Ware potato sprouting was found to be significantly ($P \leq 0.05$) influenced by the interaction effect of the temperature, sprout suppressant, cultivar and storage duration (Table 4.1, Appendix 8). Generally, dormancy break was earlier when tubers were stored at ambient store than at cold store and it was reached earlier by cultivar Shangi than by cultivar Asante and Kenya Mpya at both storage temperatures. Control treatment sprouted earlier in both storage temperatures. The rest period decreased linearly with storage time for all the cultivars at both storage temperatures. Control treatments in all the cultivars had 100% sprouting with numerous sprouts by the end of 24 weeks storage duration at both storage temperatures. At cold store, sprout emergence was first observed at week 8, 12 and 14 of the experiment for cultivars Shangi, Asante and Kenya Mpya respectively with no treatment, and dormancy end followed at week 10, 14 and 16 for cultivars Shangi, Asante and Kenya Mpya, respectively. At ambient store, cultivar Shangi started to sprout in week 3 while cultivars Asante and Kenya mpya started sprouting at week 9 of storage. Dormancy ended at week 4 for cultivar Shangi and week 10 for cultivar Asante and Kenya Mpya. The rest period of control treatment was extended by 4-6 weeks when storage temperature was lowered from 23 ºC to 10 ºC.

Table 4. 1: Effect of storage temperature and CIPC, DMN and peppermint oil treatments on Sprouting % of potato tubers

			Sprouting (%)											
			Storage duration (weeks)											
Storage	**Treat**	**Cv.**	2	4	6	8	10	12	14	16	18	20	22	24
Cold Store	Control	AS	0	0	0	0	0	30	83.33	90	100	100	100	100
	CIPC		0	0	0	0	0	0	0	0	0	0	0	0
	DMN		0	0	0	0	0	0	0	0	30	33.33	36.67	46.67
	PMO		0	0	0	0	0	0	0	0	0	30	23.33	16.67
	Control	K M	0	0	0	0	0	0	46.67	93.33	100	100	100	100
	CIPC		0	0	0	0	0	0	0	0	0	0	0	0
	DMN		0	0	0	0	0	0	0	0	0	0	0	0
	PMO		0	0	0	0	0	0	0	0	0	26.67	16.67	13.33
	Control	SH	0	0	0	20	80	100	100	100	100	100	100	100
	CIPC		0	0	0	0	0	0	0	0	0	0	0	0
	DMN		0	0	0	0	0	0	0	16.67	23.33	30	33.33	36.67
	PMO		0	0	0	0	0	0	0	33.33	23.33	16.67	10	10
Ambient Store	Control	AS	0	0	0	0	80	100	100	100	100	100	100	100
	CIPC		0	0	0	0	0	0	0	0	0	3.33	6.67	16.67
	DMN		0	0	0	0	60	63.33	63.33	63.33	63.33	63.33	63.33	63.33
	PMO		0	0	0	0	0	0	0	26.67	20	20	20	26.67
	Control	KM	0	0	0	0	80	96.67	100	100	100	100	100	100
	CIPC		0	0	0	0	0	0	0	0	0	3.33	6.67	10
	DMN		0	0	0	0	0	0	0	3.33	6.67	13.33	16.67	20
	PMO		0	0	0	0	0	0	0	30	33.33	23.33	20	26.67
	Control	SH	0	93.33	100	100	100	100	100	100	100	100	100	100
	CIPC		0	0	0	0	0	0	0	0	0	10	13.33	23.33
	DMN		0	3.33	16.67	73.33	76.67	76.67	76.67	76.67	76.67	76.67	76.67	76.67
	PMO		0	0	0	0	46.67	36.67	26.67	23.33	16.67	20	23.33	30
	LSD (5%)		ns	2.769	1.937	1.937	5.125	3.403	4.406	8.821	5.219	6.004	6.449	6.449

LSD (p≤0.05): ST 0.3705, LSD (p≤0.05): T 0.5240, LSD (p≤0.05): C 0.4538, LSD (p≤0.05): SD0.9446,

LSD (p≤0.05): ST x T 0.7410, LSD (p≤0.05): ST x C 0.6417, LSD (p≤0.05): T x C 0.9075,

LSD (p≤0.05): ST x SD 1.3358, LSD (p≤0.05): T x SD 1.8891, LSD (p≤0.05): C x SD 1.6360,

LSD (p≤0.05): ST x T x C 1.2834, LSD (p≤0.05): ST x T x SD 2.6717, LSD (p≤0.05): ST x C x SD 2.3137,

LSD (p≤0.05): T x C x SD 3.2721, LSD (p≤0.05): ST x T x C x SD4.6274

Legend: PMO- Peppermint oil, CIPC- Chlorpropham, DMN- 1,4-Dimethylnapthalene, Treat= treatment, Cv.= cultivar,

AS= Asante, KM= Kenya Mpya, SH= Shangi, ns= not significant

Differences in cultivar response to storage temperature were observed. Cultivars Asante and Kenya Mpya exhibited similar dormancy length at ambient store but at cold store, cultivar Kenya Mpya exhibited a longer rest period that cv. Asante. Cultivar Shangi which showed the shortest rest period of 4 weeks at ambient store extended the rest period by 6 weeks similar to that of cv. Kenya Mpya which had a rest period of 10 weeks at ambient store.
CIPC performed as the best sprout inhibitor in all potato cultivars compared to DMN and Peppermint oil treatments at cold store. While all the control treatment which were stored at 10ºC had 100% sprouting on storage week 20, tubers treated with CIPC remained dormant 20 weeks after the treatments were applied. At the same time, sprouting was 30-33% for cultivars Shangi and Asante tubers treated with DMN while cultivar Kenya Mpya had 0% sprouting (Table 4.1). On the other hand, sprouting was 16-30% for peppermint oil (PMO) treated tubers among the 3 cultivars.

By week 22 of storage, tubers treated with CIPC had started sprouting but the sprouts remained at 'peeping' stage and remained to be less than 3mm up to the end of 24 weeks storage therefore sprouting % was recorded as zero.

At ambient storage, CIPC presented the most efficient sprout inhibitory effect leading to a 23.3%, 16.7% and 10% of sprouting for cultivars Shangi, Asante and Kenya Mpya respectively at the end of the 24 weeks storage period. Cultivar differences were not observed in response to CIPC treatment in cold storage as no sprouting was recorded in all the cultivars. However, at ambient storage, cultivar Shangi recorded significantly higher sprouting % than Asante and Kenya Mpya. Once sprouting began, it increased gradually with storage time.

Differences in sprouting among cultivars receiving similar treatments were observed with DMN treatment at both storage temperatures. Generally, DMN treatment was more effective in delaying sprout emergence, reducing the rate of sprouting and sprouts growth at cold than ambient storage. While DMN treated tubers which were stored at 23ºC had nearly 80% sprouting at the end of 24 weeks storage, tubers treated with DMN at 10ºC remained at low sprouting levels (lower than 50%). DMN treatments did not prevent the onset of sprouting in cultivars Shangi and Asante in ambient store but it greatly reduced the rate of sprouting compared to the control treatment (Table 4.1). Although the control and DMN treatments

began sprouting at the same time in cultivar Shangi and Asante tubers, to some extent DMN was able to suppress sprouting rate and as a result, sprouting was 76.67% and 63.33% for cultivars Shangi and Asante respectively. However, in cultivar Kenya Mpya, DMN treatment completely inhibited sprouting until week 16 and at the end of 24 weeks; sprouting % was only 20%. At cold store, DMN treatments effectively suppressed sprouting until week 16 and 18 for cultivars Shangi and Asante respectively. In cultivar Kenya Mpya, the effectiveness of DMN treatment was equal to that of CIPC in suppressing sprouting. The tubers began sprouting towards the end of the experiment but the sprouts remained at 'peeping' stage (<3mm) hence % sprouting was recorded as zero. Sprouting was complete on control treatments at the end of week 4 and 10 for cultivars Shangi and Asante respectively in ambient store while at the same storage period, DMN treatments did not prevent sprouting but they had a moderate inhibitory effect on rates of sprouting compared to control treatment. At cold store, dormancy end was delayed until week 10, 14 and 16 for the control treatment tubers of cultivars Shangi, Asante and Kenya Mpya. At the same storage time, there was 100% sprout inhibition by DMN treatment in all cultivars. At ambient storage, sprouting rate increased up to week 12 (63.33%) after which no further increase in sprouting occurred for cultivar Asante tubers. Similarly, in cultivar Shangi, sprouting increased up to week 10 above which no more increase in sprouting occurred. DMN appeared to be a better sprout inhibitor for cultivar Kenya Mpya as compared to Shangi and Asante potato tubers at both storage conditions.

In general, peppermint oil treatment was found to suppress sprouting and sprout growth of emerged sprouts in both storage temperatures. It was not as effective as CIPC treatment but it was more effective than DMN treatments for cultivar Shangi and Asante at both storage conditions. However, DMN was more effective than peppermint oil in cultivar Kenya Mpya at the same storage. Peppermint oil performed as a very good sprout suppressant in all cultivars at cold store than ambient store. Peppermint oil suppressed sprouting very efficiently in all the cultivars and tubers only began sprouting towards the end of the experiment (week 16 for Shangi, and week 20 for both Asante and Kenya Mpya) at cold store. At ambient store, tuber sprouting began at week 10 for cultivar Shangi and week 16 for cultivar Asante and Kenya Mpya tubers. More than 70% treated tubers remained non-sprouted by the end of 24 weeks in all the cultivars at 23ºC while at 10ºC more than 80% of

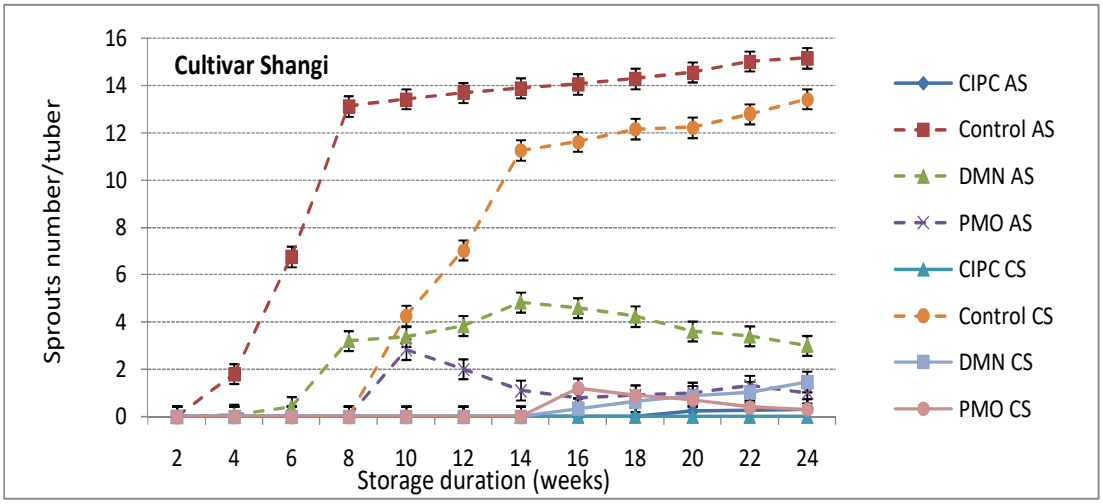
treated tubers remained non-sprouted. At the end of storage, sprouting was 30% for cultivar Shangi which was a reduction from an initial 46.7 %, 26.7% for cultivar Kenya Mpya which was a reduction from 33.3% at ambient store. At cold store, sprouting was 10%, 16.7% and 13.3% which was a reduction from 33.3%, 30% and 26.7% for cultivars Shangi, Asante and Kenya Mpya respectively. With every retreatment, the number of sprouted tubers, sprout length and number of sprouts started to reduce as a result of the treatment induced necrosis occurring on the sprouts. In both storage conditions, cultivars Asante and Kenya Mpya receiving peppermint oil treatment began sprouting at the same time. However, cultivar Asante maintained a higher sprouting % than Kenya Mpya at cold store while Kenya Mpya had a higher sprouting % than Asante at ambient store (Table 4.1). At both temperatures, sprout emergence was earlier for cultivar Shangi than Asante and Kenya Mpya receiving peppermint oil treatment. Generally, the rate of sprouting increased with increased storage in all the treatments except for peppermint oil treatment. Cultivar Asante tubers had lower levels of sprouting than Shangi tubers, irrespective of the treatment. All the tubers in all the treatments stored at cold store appeared firm than those at ambient store.

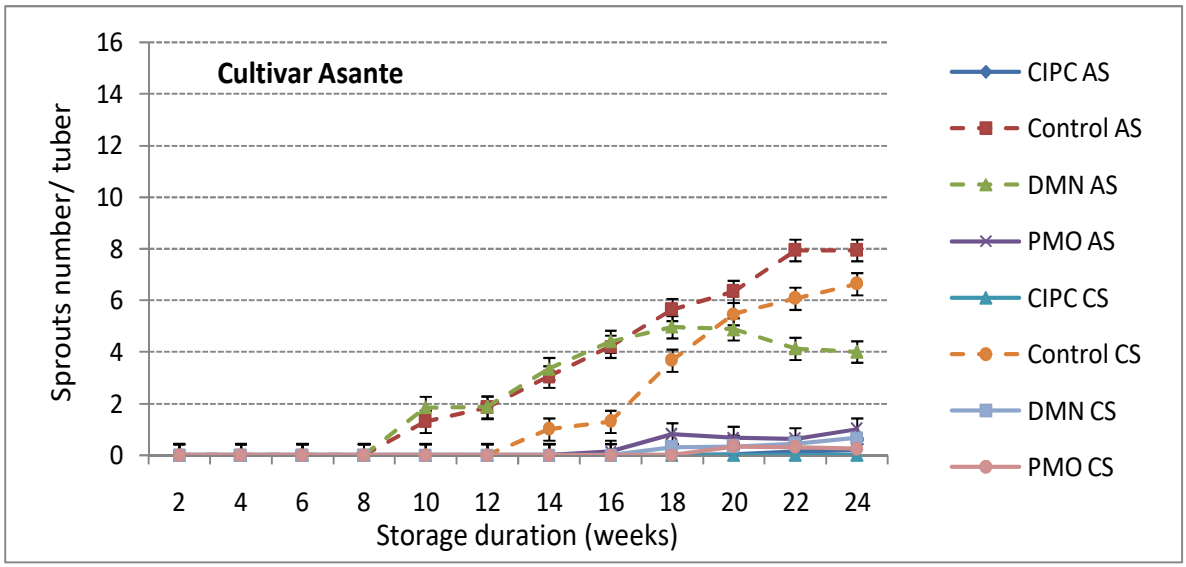
4.3.2. Number of sprouts per tuber

There was a significant ($P \leq 0.05$) interaction among storage temperature, treatment, cultivar and storage duration. Sprout development was first observed in control treatment of cultivar Shangi at both ambient and cold store (Figure 4.1). As a result, control treatments of cultivar Shangi maintained the highest number of sprouts per tuber at both storage conditions. Additionally, in all the treatments, number of sprouts per tuber were high in ambient than cold store. It was also observed that the number of sprouts increased with storage time especially in control and CIPC treatments at both storage conditions (Figure 4.1). Generally, the untreated tubers gave significantly higher number of sprouts per tuber compared to the treated tubers. At the end of the experiment, control treatment had 15.2, 7.9 and 15.1 sprouts per tuber for cultivars Shangi, Asante and Kenya Mpya respectively at ambient store. At cold store the number of sprouts per tuber was 13.4, 6.6 and 12 for cultivars Shangi, Asante and Kenya Mpya respectively at the end of the experiment.

CIPC treated potatoes produced the lowest number of sprouts per tuber at the end of 24 weeks storage in ambient store. At cold store, CIPC treated tubers sprouted towards the end

of the experiment but the sprouts remained at peeping stage (sprout length <3mm) hence number of sprouts was recorded as zero for all the cultivars. For the DMN treatments, sprout number varied between storage type, and the lowest and the highest number of sprouts on tubers was found in cold and ambient store respectively. At ambient store, the number of sprouts per tuber varied among cultivars. At the end of the experiment, sprouts number per tuber were 3, 4 and 0.6 for cultivars Shangi, Asante and Kenya mpya respectively. On the other hand, at cold store number of sprouts per tuber was 0, 1.5 and 0.7 for cultivars Kenya Mpya, Shangi and Asante respectively. Generally, sprout emergence was greatly delayed by reduced storage temperature in all the treatments and as a result the lowest number of sprouts per tuber was recorded for all treatments at cold store. Although sprouting on cultivar Shangi tubers was observed at the beginning of the experiment for the DMN treatment, this treatment had only 3 sprouts per tuber at the end of the experiment. Despite sprouting early in the experiment, DMN treatment had lower number of sprouts per tuber at the end of the experiment compared to the control treatment. The number of sprouts at the end of the experiment had reduced for cultivar Shangi and Asante tubers treated with DMN. This was due to the falling off of dry necrotic sprouts resulting from DMN treatment during handling. Probably due to the late sprouting in cultivar Kenya Mpya, the number of sprouts per tuber increased with time up to the end of experiment.





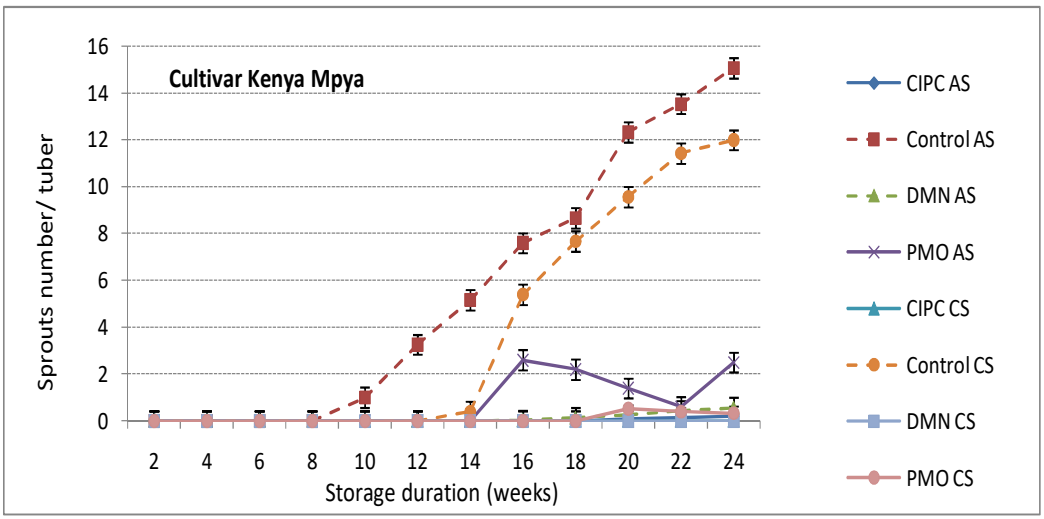


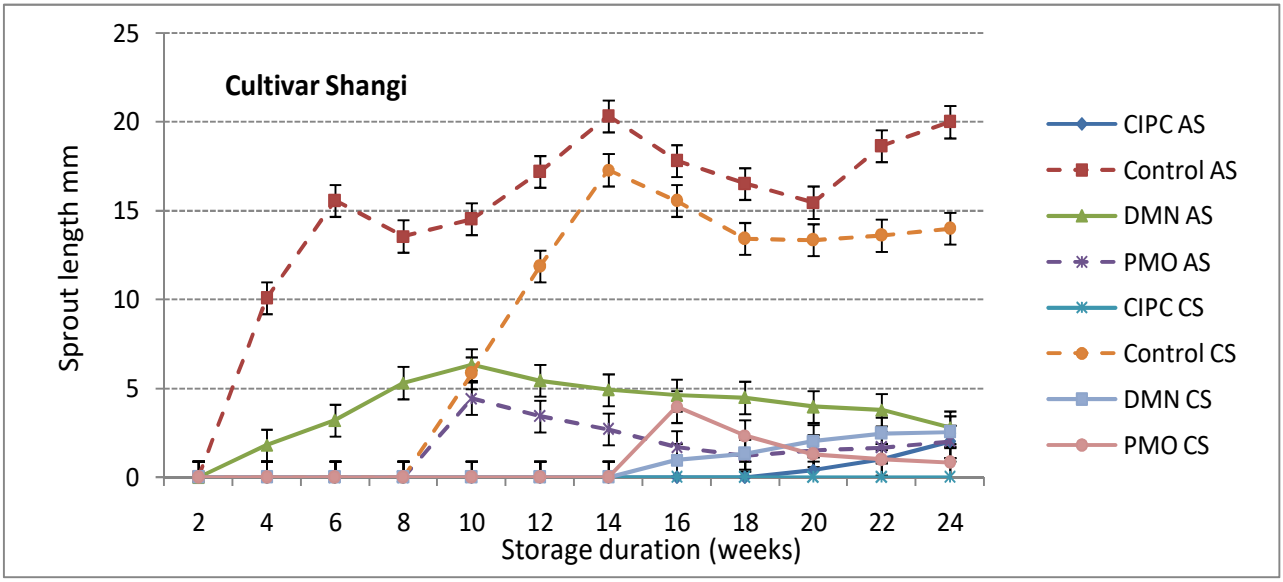
Figure 4. 1: Effect of storage temperature on the number of sprouts (number/tuber) of tubers from three potato cultivars treated with CIPC, DMN and peppermint oil over 24 weeks storage duration.
***Legend*: AS= Ambient store, CS=Cold store**

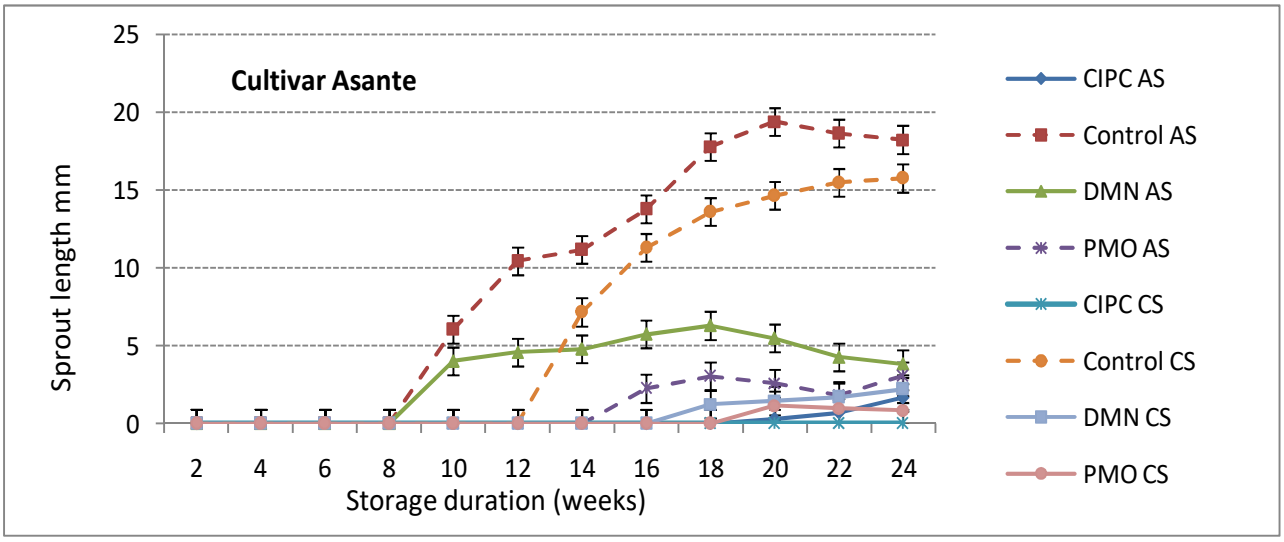
The number of sprouts on tubers from DMN treatment was higher than on tubers from the peppermint oil treatment at both temperatures except in cultivar Kenya Mpya which had higher sprout number in peppermint oil treatment than DMN treatment.

Peppermint oils presented an efficient sprout inhibitory effect leading to a <1.5 sprout number per tuber at ambient store and <0.5 at cold store in all the cultivars at the end of experiment. It is worth noting that the number of sprouts increased initially in peppermint oil treated tubers but retreatment with peppermint oil led to withering of the emerged sprouts at both temperatures leading to a decline in number of sprouts per tuber. As the concentration within the package went down, more sprouts would grow. Generally, cultivar Shangi induced the highest number of sprouts in most of the treatments at both storage temperatures irrespective of the treatment.

4.3.3. Sprout length

Sprout length was significantly ($P \leq 0.05$) influenced by the interaction effect among storage temperature, cultivar, treatment and duration of storage. Sprout growth varied among cultivars. Within a cultivar, sprout length varied among treatment and duration of storage. Sprout growth was more rapid under ambient storage than low temperature storage across all the treatments. Generally, Sprouting started earlier in the experiment for control treatments and consequently highest sprout length was observed for the control at both storage temperatures. Sprout lengths recorded were 20mm, 18.24mm and 23.15mm for cultivars Shangi, Asante and Kenya Mpya respectively at temperature of 23±2ºC. On the other hand, sprout length recorded were 16.6mm, 15.76mm and 12.98mm for cultivars Shangi, Asante and Kenya Mpya respectively stored at reduced tempertaure. Reducing storage temperature reduced sprout growth in control treatment. Differences in sprout growth among cultivars treated with different chemicals were clearly observed throughout the experimental duration. All the treatments were more effective in suppressing sprout elongation at cold storage than ambient storage. Among the treatments, CIPC was the most effective in suppressing sprout growth followed by peppermint oil and DMN treatments. At the end of 24 weeks storage, the shortest sprout length was found in CIPC treated tubers; 2mm, 1.7mm and 1.8mm for cultivars Shangi, Asante and Kenya Mpya respectively at ambient store while 100% sprout growth inhibition was recorded at cold storage.





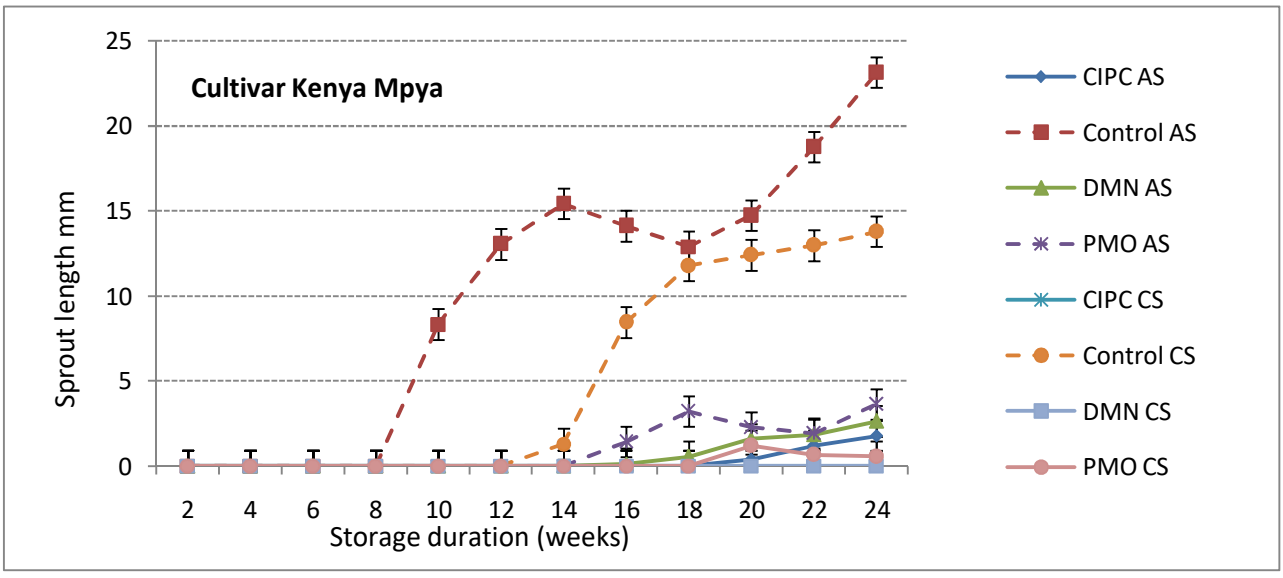


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Figure 4. 2: Effect of storage temperature on sprout length (mm) of potato tubers from three cultivars treated with CIPC, DMN, peppermint oil over 24 weeks storage duration.

Legend: AS= Ambient store, CS=Cold store

Peppermint oil treatments resulted in sprout lengths of 2mm, 2.1mm and 2.6mm for cultivars Shangi, Asante and Kenya Mpya tubers respectively at ambient storage and it was less than 1mm at cold storage in all the cultivars.

DMN treated tubers had 2.8mm, 3.8mm and 2.6mm sprout length for cultivars Shangi, Asante and Kenya Mpya respectively at ambient storage and 2.5mm, 2.2mm and 0mm for cultivars Shangi, Asante and Kenya Mpya tubers respectively at cold storage. Although sprouting was not inhibited by the DMN treatment at ambient storage in cultivar Shangi and Asante at the beginning of the experiment, sprout elongation was greatly suppressed and shorter sprout length was recorded at the end of storage period compared to the control. Cultivar Kenya Mpya was more responsive to DMN treatment than cultivars Shangi and Asante at both storage conditions. Lengths of sprouts in peppermint oil treatments were limited by necrosis of sprout tips resulting from repeated treatment. At 10±2ºC, lengths of sprouts were limited by late sprouting. Once sprouting began, sprout lengths of tubers increased gradually for all treatments except peppermint oil treatments during the experiment. The length of the longest sprout was frequently arrested by sprout tip necrosis.

4.4. DISCUSSION

Application of sprout suppressants in combination with storage temperature are important post-harvest management tools of ware potato quality for long term storage. The results of the reported research on sprouting and sprout growth evidently showed that complete sprout inhibition can be achieved for 24 weeks under low temperature storage of 10ºC and 18 weeks under ambient storage of 23ºC with a single application of CIPC at a concentration of 22 mg kg^{-1} irrespective of cultivar. Effectiveness of sprout suppressants has been reported to be higher at reduced storage temperatures than at high temperatures (Sanli et al., 2010; Mehta and Kaul, 1991; Mehta, 2004). Mehta and Kaul (1991) using three sprout inhibitors; maleic hydrazide (MH), CIPC and isopropyl phenylcarbamate (IPC) at storage temperatures of 20–30°C and 16–30°C found the treatments to be more effective in suppressing sprouting at low temperature than at high temperatures. CIPC ability to inhibit sprouting decreased with increasing storage time and temperature. Storage temperature as well as storage duration has been found to have a substantial effect on the CIPC residue levels present in the potato tuber.

Mondy et al. (1992) reported that tubers stored at 5ºC contained higher CIPC residue levels than those stored at 20ºC. CIPC residue levels vary with storage duration and it is high immediately after treatment then declines with storage time (Singh and Ezekiel, 2010; Sakaliene et al., 2008; Singh and Ezekiel 2010; Mondy et al., 1992; Corsini et al., 1979). Storage temperature has been shown to affect CIPC residue levels within a tuber. Sprout suppression ability of CIPC has been found to be more effective at temperature of 15 °C or below and its efficacy decreases at temperature higher than 15 °C (Ezekiel et al., 2005; Mehta et al., 2007, 2010; Sanli et al., 2010; Mondy et al., 1992; Wessel and Wustman, 1990). CIPC was shown to reduce sprouting and suppress sprout growth in potatoes up to 16 weeks of storage at 10-32ºC storage temperature (Mehta and Ezekiel, 2002) while at storage temperature of 7.2 °C, it effectively suppressed sprout growth for up to ten months in storage (Lewis et al., 1997). Van Vliet (1970) reported that CIPC at 10-20 ppm controlled sprouting for 6 months at 10°C. Mehta (2004) while working with maleic hydrazide and CIPC at storage temperature of 14-30ºC reported significant reduction in respiration of treated tubers that was positively correlated to the rate of sprouting and sprout growth.

DMN proved to be an effective sprout suppressant when tubers were stored at cold store than at ambient store. The sprouting potential of stored ware potato tubers treated with DMN varied between storage temperatures and among cultivars and it increased with increasing storage time. Tubers stored at high temperature emerged from dormancy prior to those stored at lower temperatures. Sprouts on DMN-treated tubers of all cultivars stored at cold store maintained sprout length of <2.6 mm throughout the study while that of tubers in ambient stored had longer sprouts (up to 6mm) confirming the sprout suppressing effect of the combined effect of reduced storage temperature and DMN treatment. The results of our work agree with earlier studies done on potato tubers. The residue levels of DMN in treated tubers have been shown to be high when tubers are stored at reduced temperature. Knowles et al. (2005) treated seed of three different cultivars stored at temperatures of 4ºC, 7ºC and 9ºC. Resulting tuber residues 50 days after the last treatment were 5.1 ppm, 2.0 ppm and 1.5 ppm at 4ºC, 7ºC and 9ºC respectively, demonstrating a greater loss of DMN for tubers stored at higher storage temperatures. In the same study, the authors reported that DMN-treated tubers stored at the higher temperatures contained significantly lower residues of DMN at the end of storage than those held at lower temperature. However, the residue levels were still in excess compared to the levels found in untreated tubers. This could be the reason why despite the

DMN treated tubers of cultivars Asante and Shangi sprouting at the same time as untreated tubers at ambient store, sprouting % and sprout growth were greatly reduced. Cultivar differences in response to DMN treatment was observed at both storage conditions. The best results were recorded in cultivar Kenya Mpya equaling the effectiveness of CIPC at 10ºC. Similarly, Lewis et al. (1997) had reported that two applications of DMN at rates of 200 and 300 mg kg^{-1} were equal to CIPC in suppressing sprout elongation after 295 days in storage at 7ºC. Based on the these findings, it is thought that DMN treated tubers at cold store contained higher residue levels enough to suppress sprouting as compared to tubers at ambient store. The onset of sprouting was fairly consistent in both temperatures occurring first in cultivar Shangi and last in cultivar Kenya Mpya. DMN treatments suppressed sprout growth and greatly reduced sprout elongation at both temperatures. These results are similar to those reported previously by several researchers who reported reduced sprout elongation of tubers treated with DMN and store at 10-17^{o}C compared to untreated tubers (Beveridge et al., (1981b; Stephen and Duncan, 1984; Lewis et al., 1997).

This study found that peppermint oil treatments effectively suppressed sprouting and elongation of emerging sprouts at both storage temperatures. However, it was not by prolonging the natural rest period but it was by physically destroying the emerged sprouts. The best results were obtained at cold store than at ambient store. The results of this study are in agreement with the findings of earlier workers using various monoterpenes (Coleman et al., 2001; Elsadr and Waterer, 2005; Daniels-Lake et al., 1996; Vaughn and Spencer, 1991; Gómez-Castillo, 2013; Mehta and Kaul, 2002). The sprouting development observed in this experiment could be due to the reduction of available peppermint oil compound within the package caused by leakage and ventilation and it also could be due to the compounds absorbed by the tubers that were metabolized to less toxic forms over time ((Bång 2007; Kleinkopf and Frazier, 2002)). Both factors could have allowed the tubers to resume sprouting and sprout growth. The greater suppression of sprouting and sprout growth at reduced temperature could be attributed to higher vapor concentration of the peppermint oil within the package at low temperature compared to high temperature. Coleman et al. (2001) reported that treatment with peppermint oil in combination with storage at 10ºC suppressed sprout growth maintaining a sprout length of <5mm while the control treatment had sprout length >30mm after 8 weeks. Additionally, storage at 25ºC resulted in sprout length of

9.2mm and 68.6mm for menthone and control treatment respectively at the end of 4 weeks in storage. Peppermint oil retreatment led to a significant reduction in sprouting rate, number of sprouts per tuber and sprout length after sprout emergence in both storage temperatures. However, the best results were obtained at cold store than at ambient store. When the treatment was repeated, the duration of sprout suppression was also increased. Previous studies have suggested repeated applications of essential oil are necessary to achieve effective sprouting control for prolonged storage (Frazer et al., 2004).

The sprouting response of control treatment showed significant differences between storage temperatures and among cultivars. Cultivar Shangi had a shorter dormancy period in both temperature than Asante and Kenya Mpya. These results are consistent with previously established differences in the lengths of dormancy for these cultivars (Shangi<Asante=Kenya Mpya) (NCPK, 2015). In addition, the results show that a cultivar exhibiting short rest period in ambient storage will behave similarly in cold storage when compared to a cultivar with a longer rest period. The effect of storage temperature on sprouting and sprout growth has been studied previously by several researchers. It is reported that within the range of 3 °C to 20 °C, tubers stored at a lower temperature have a longer period of natural dormancy than those stored at a higher temperature (Wiltshire and Cobb, 1996; Davidson, 1958). Additionally, the rate of sprout elongation increased with increasing storage temperature between 8 and 20ºC (Banerjee and Bhargava, 1992). Sprouting and sprout growth differs with genotypes but it generally increases with storage temperature and time (Carli et al., 2010; Banerjee and Bhargava, 1992).

5.5. CONCLUSION

The results of the reported research clearly shows that significant suppression of sprouting, sprout growth and sprouts number can be achieved through cold storage in combination with sprout suppressants than ambient storage of tubers treated with sprout suppressants. Kenya Mpya emerged as the best cultivar in terms of storability after treatment with CIPC and DMN. The high sprouting capacity of Shangi tubers indicated that Shangi tubers cannot be stored for more than four weeks without treatment with sprout suppressants. Additionally, low temperature storage can be used to further enhance the keeping quality of potato tubers.

CHAPTER FIVE: EFFECT OF PREHARVEST FOLIAGE APPLICATION OF PACLOBUTRAZOL AND ETHEPHONE ON SPROUT SUPPRESSION OF WARE POTATO DURING STORAGE

Abstract

The effect of two foliar applied plant growth regulators; Paclobutrazol (PBZ) and Ethephon in inhibiting post- harvest ware potato sprouting of three potato cultivars with varying dormancy length; short to medium dormancy were examined under the tropical climate of Kenya. The experiment was conducted in the open field for two seasons of long and short rains. Application rate of 250mg/L PBZ and 500ppm ethephone as foliar spray was done twice during growth period. The first application was done at early tuber initiation while the second application was done two weeks after full bloom. After harvest and curing of tubers, the experiment was conducted at ambient conditions (23^{o}C) in the laboratory and at reduced temperature (10^{o}C) where data was collected on: days to dormancy end, sprouting %, number of sprouts per tuber, sprout length, weight loss and rotting incidences. Paclobutrazol treatment prolonged tuber dormancy period by 31 days in cultivar Shangi and approximately 21 days in cultivar Asante and Kenya Mpya. In addition, PBZ treatment slowed weight loss. Ethephon treatment showed no effect in delaying dormancy break and had no effect on dormancy period, sprouting percentage and weight loss. Tuber decay was not affected by the treatments. At cold store, the treatments were not effective in delaying sprout emergence. However, reduced temperature significantly increased dormancy period by 50-67 days. The study shows that PBZ is effective in extending potato tuber dormancy on short-term basis at 23^{o}C and reduces post-harvest weight loss of potatoes.

Key words: Paclobutrazol, ethephon, preharvest, temperature, sprouting

5.1 Introduction

Post harvest loss is an important factor limiting long term potato storage in Kenya. Annually, Kenya losses about 815,000 tonnes of harvested potato tubers; which represents a value of around KES 12.9 billion (Kaguongo et al., 2014). Potato tuber dormancy is affected by both preharvest and postharvest factors (Suttle, 2004). At harvest, potato tubers are dormant and will not sprout even under ideal sprouting conditions. This dormancy is however lost gradually with storage time and sprouting begins. The natural dormancy is referred to as endodormancy and it is primarily controlled by the physiological factors arising from within (Anderson et al., 2001). The length of the dormancy period largely depends on the cultivar and to some extent the environmental conditions, hormones and other physiological factors (Burton, 1978; Sonnewald and Sonnewald, 2014). Sprouting is one of the major causes of quality loss in stored ware potato. It leads to loss of marketable tubers, loss of tuber quality and loss of salable weight (Kleinkopf et al., 2003). In addition, sprouting leads to physiological changes in tubers that reduce their nutritional as well as processing qualities (Suttle, 2003). It is therefore important not only to produce high yields but also to have effective sprout inhibition during storage to manage potato quality. This is achievable by either storing tubers in low temperature or treatment with sprout suppressing agents (Khanbari and Thompson, 1996). Although temperature offers a solution to control sprouting; other alternative methods need to be exploited. Moreover, low temperature (2-5^{o}C) causes degradation of starch to sugar which in turn causes accumulation of reducing sugar resulting to increased tuber sweetness and unacceptable dark brown fry and crisps colour (Khanbari and Thompson, 1996).

Chemical sprout suppressants and natural compounds have been widely used to control sprouting in storage. Chlorpropham (CIPC) has been the primary method used to control sprouting in long term storage. Other chemical compounds known to inhibit sprouting are substituted napthalenes, ethylene, essential oils, jasmonates and hydrogen peroxide based materials (Kleinkopf et al., 2003; Afek et al., 2000). Although these chemicals have been found to be effective in controlling ware potato sprouting, there are concerns of chemical residues which have prompted the search for more alternative sprout control agents (Suttle, 2003). Several studies have found pre-harvest foliar application or soil drench with paclobutrazol (PBZ) to be efficacious in suppressing growth in a wide range of plant species

(Starman and Williams, 2000; Bañónet et al., 2002; Balamani and Poovaiah, 1985). It is reported that PBZ is a gibberellins biosynthesis inhibitor that inhibits cell elongation thereby retarding growth (Hedden and Graebe, 1985; Balamani and Poovaiah, 1985).

Endogenous ethylene has been proposed to play a significant role in tuber dormancy regulation (Suttle, 2004). Pre-harvest and post-harvest applications of the ethylene-releasing agent ethephon in potatoes have also been report to result in significant extensions of tuber dormancy (Cvikrova et al., 1994). Potato tubers produce limited quantities of ethylene (Rylski et al., 1974). Producing potatoes throughout the year is not practical and therefore long term storage measures need to be sought. In this view, pre-harvest treatment with suitable growth inhibitors that can suppress sprout growth with minimal or no adverse effect on yield and quality of tubers will be beneficial compared to the post harvest application of CIPC and other chemical sprout suppressants. Moreover, pre-harvest foliar application is much easier than post harvest application of these chemicals. In the present study we have determined the effect of PBZ and ethylene pretreatment on dormancy period of tubers of plants grown under field conditions and stored under different storage temperature.

5.2 MATERIALS AND METHODS

5.2.1 Site description

Kabete Field Station

The field experiment was conducted at Kabete Field Station of the University of Nairobi which lies at an altitude of 1737 m above sea level and on latitude 1^0 15' S and longitude 36^0 44' E (Mburu, 1996). It falls under the Upper Midland (UM) agro-ecological zone number three (Jaetzold et al, 2006). The area has a bimodal rainfall pattern with peaks in April and November. The annual rainfall is around 1000 mm which is spread over the long rain (March to May) and short rain (October to December) seasons. The site has maximum and minimum mean temperatures of 24.3^0 and 13.7^0C respectively. The dominant soils are Nitosols, which are very deep, well-drained, dark reddish, deep friable clay type resistant to erosion (Jaetzold et al., 2006).

5.2.2 Plant material

Certified potato seeds of three commercially cultivated cultivars namely Shangi, Asante and Kenya mpya were sourced from Kenya agricultural and livestock research institute (KALRO) Tigoni. The experiment was between april- july 2013 (season 1) and between October-january 2014 (season 2). The tubers were field grown in 4x4 plots with spacing of 0.3x0.75m. Phosphorus was applied as diammonium phosphate at planting time at a rate of 150 kg P ha^{-1} and nitrogen was side dressed after full emergence at a rate of 100 kg N ha^{-1} in the form of urea. Standard agronomic practices recommended for potatoes including ridging, pest control and weeding were followed. The field experiment was arranged in randomized complete block design with split plot arrangement while in the laboratory experiment; factorial treatments arrangement with 3 cultivars x 3 treatments was used.

5.2.3 Treatment application

At early tuber initiation (approximately 42 days after planting), the plants were treated with paclobutazol (PBZ) (Austar chemicals direct pty ltd, Australia) at the rate of 250mg/L as foliar spray. PBZ was diluted in distilled water and 5ml solution applied per plant as a fine spay. The control plants were treated with distilled water of equal volume. Similarly, at early flower initiation, the plants were treated with ethephon (SIGMA Company, Sigma-Aldrich Co., Germany) at the rate of 2500ppm as foliar spray. Two weeks after full bloom, a second application of the treatments was done.

Tubers were harvested at the end of July 2013 and January 2014. Freshly harvested potato tubers free of any evident disease and without any signs of sprouting were selected and cured for 14 days under the prevailing ambient conditions. 20 tubers were selected for every treatment, weighed and placed in khaki bags and labeled then samples were randomly distributed on shelves. The treatments were replicated three times.

5.2.4 Storage conditions

The experiment was conducted separately at two storage conditions, at ambient storage with temperature of 23±2^{o}C and at cold storage with temperature of 10±2^{o}C. Due to differences in

time taken for complete dormancy end, data from the two storage conditions was analysed and presented separately.

5.2.5 Data collection

Data were collected on the following:

i. Dormancy period

The dormancy period was counted as the number of days from harvesting to sprouting of 80% of the tubers (16 out of 20 sprouted tubers in each sample) with at least one sprout ≥3 mm. After the first sprout emerged, tubers were monitored after every three days to accurately determine dormancy end.

ii. Sprouting %

Sprouting was calculated as the percentage of the number of sprouted tubers in each sample (tubers with sprout length of ≥3mm) and averaged on per sample basis.

iii. Sprout length (mm)

Sprout length was measured as height from the base of the sprout to the tip of the sprout. The measurements were done on the longest sprout in every sprouted tuber in each replicate. Twenty tubers per replicate were measured and averaged on per tuber basis. A tuber was considered to have sprouted when at least one 3mm long sprout was present

iv. Number of sprouts per tuber

This was done by counting all the sprouts with at least 3mm sprout length in every tuber. The sprouts number was then averaged on per tuber basis.

v. Sprout thickness (mm)

The thickness of the longest sprout of each tuber was measured and then the average of sprout thickness per tuber was calculated.

vi. Weight loss

The weight of 20 tubers in each treatment was weighted before the tubers were put into storage. The final weight was done by weighing the samples at the end of 13 weeks of

storage. Weight loss was calculated as the ratio of weight change to the initial weight which was expressed in a percentage.

vii. Tuber rotting

Rotting incidences were evaluated by observing each tuber for any sign of decay and the number of rotten tubers per sample recorded.

5.2.6 Data analysis

All data was subjected to analysis of variance in Genstat software (v. 15, VSN, UK, 2010) with duration of storage, treatments and replicates as factors and % sprouting, sprouts number, sprout length, sprout thickness and weight loss as variables. Data from each storage temperature was analyzed separately. Tukey's least significant difference at 5% probability level was used for mean separation

5.3 RESULTS

5.3.1 Dormancy period

The main effects of treatment and cultivar as well as interactions had significant ($P \leq 0.05$) influence on dormancy period. At ambient storage, treatment and cultivar interacted significantly to increase dormancy period by 31, 21 and 22 days in cultivars Shangi, Asante and Kenya Mpya, respectively (Table 5.1). The shortest dormancy period (24 days) was recorded in cultivar Shangi tubers without treatment. With ethephon treatment, dormancy period was 27 days and 55 days with PBZ treatment. The longest dormancy period of 89 days was recorded for cultivar Kenya Mpya tubers treated with PBZ. Asante tubers treated with PBZ recorded a dormancy period of 81 days. Significant differences between ethephon and control treatments were not observed. Cultivar Asante tubers recorded 58 and 60 days for ethephone and control treatments respectively. Cultivar Kenya Mpya tubers recorded 69 and 67 days for ethephone and control treatments respectively.

At cold storage, only the main effects of cultivar and treatment had significant ($P \leq 0.05$) effect on dormancy period (Table 5.2). The interaction between treatment and cultivar had

no effect on dormancy period. Cultivar Shangi tubers had the shortest dormancy period recording a dormancy period of 91, 93.3 and 93.7 days for untreated control, ethephon and PBZ treatments respectively. The longest dormancy period of 126 days was recorded for cultivar Kenya mpya tubers treated with PBZ and ethephon while untreated tubers recorded 120.3 days. Cultivar Asante tubers recorded 110days irrespective of the treatment.

Generally, at ambient store, treatment with PBZ increased dormancy period for all the tubers compared to ethephon and control treatment while at cold store, dormancy period was increased as a result of low temperature and not treatment (Tables 5.1- 5.2).

Table 5. 1: Effect of PBZ and Ethephon treatment on dormancy period of 3 potato cultivars during storage at ambient temperature

	Dormancy period (Days)		
	Cultivars		
Treatment	Asante	Kenya Mpya	Shangi
Control	60^{d}	67^{c}	24^{f}
Ethephon	58^{de}	69^{c}	27^{f}
Paclobutrazol	81^{b}	89.33^{a}	55^{e}

Means with different letters in each character indicate significant differences according to Tukey's protected least significant difference test at 5% probability level

Table 5. 2: Effect of PBZ and Ethephon treatments on dormancy period of 3 potato cultivars during storage under low temperature

	Dormancy period (Days)		
Treatment	Asante	Kenya Mpya	Shangi
Control	110^{b}	120.33^{a}	91^{c}
Ethephon	110^{b}	126^{a}	93.33^{c}
Paclobutrazol	110.33^{b}	126^{a}	93.67^{c}

Means with different letters in each character indicate significant differences according to Tukey's protected least significant difference test at 5% probability level

5.3.2 Sprouting (%)

At ambient storage, tuber sprouting was significantly ($P \leq 0.05$) influenced by the main effects of the treatment, cultivar and storage duration as well as the interactions among treatments, cultivars and duration of storage (Table 5.3, Appendix 10). Tuber sprouting for the ethephon and control treatments began in week 3 in cultivar Shangi (66.67% and 53.33% for control and ethephon treatment respectively), week 8 for cultivar Asante (50% and 53.33% for control and ethephon treatment respectively) and week 9 for cultivar Kenya Mpya (43.33% and 33.33% for control and ethephon treatment respectively (Table 5.3).

Table 5. 3: Effect of PBZ and ethephon treatments on sprouting % of 3 potato cultivars during 13 weeks storage at ambient temperature of 23±2°C.

		Sprouting %												
		Storage duration (weeks)												
Treatment	Cultivar	1	2	3	4	5	6	7	8	9	10	11	12	13
Control	Asante	0	0	0	0	0	0	0	50	83.33	100	100	100	100
	Kenya Mpya	0	0	0	0	0	0	0	0	43.33	86.67	100	100	100
	Shangi	0	0	66.67	96.67	96.67	100	100	100	100	100	100	100	100
Ethephone	Asante	0	0	0	0	0	0	0	53.33	93.33	96.67	100	100	100
	Kenya Mpya	0	0	0	0	0	0	0	0	33.33	83.33	96.67	100	100
	Shangi	0	0	53.33	83.33	96.67	96.67	100	100	100	100	100	100	100
PBZ	Asante	0	0	0	0	0	0	0	0	0	0	70	90	96.67
	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	20	46.67	86.67
	Shangi	0	0	0	0	0	0	76.67	86.67	96.67	100	100	100	100
	LSD (5%)	ns	ns	4.561	4.997	4.856	3.331	3.331	12.57	10.33	18.09	15.08	19.42	4.856
	LSD (p≤0.05): T 1.506, LSD (p≤0.05): C 1.506, LSD (p≤0.05): SD3.134, LSD (p≤0.05): T x C 2.608, LSD (p≤0.05): T x SD 5.429, LSD (p≤0.05): C x SD 5.429, LSD (p≤0.05): T x C x SD 9.403													

Legend: T= Treatment, C= cultivar, SD= Storage duration, ns= not significant

Table 5. 4: Effect of PBZ and ethephon treatments on sprouting % sprouting of 3 potato cultivars during 18 weeks storage at ambient temperature of 10±2°C.

		Sprouting %																
		Storage duration (weeks)																
Treatment	Cultivar	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Control	Asante	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	90	100	100
	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	63.33	93.33
	Shangi	0	0	0	0	0	0	0	0	0	0	0	53.33	80	100	100	100	100	100
Ethephon	Asante	0	0	0	0	0	0	0	0	0	0	0	0	0	0	43.33	90	96.67	100
	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50	80
	Shangi	0	0	0	0	0	0	0	0	0	0	0	50	70	96.67	100	100	100	100
PBZ	Asante	0	0	0	0	0	0	0	0	0	0	0	0	0	0	60	93.33	100	100
	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	46.67	80
	Shangi	0	0	0	0	0	0	0	0	0	0	0	40	70	93.33	100	100	100	100
LSD (5%)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	9.27	12.07	7.633	10.92	10.13	14.23	3.331

LSD (p≤0.05): T 0.801, LSD (p≤0.05): C 0.801, LSD (p≤0.05): SD 1.962, LSD (p≤0.05): T x C 1.388, LSD (p≤0.05): T x SD 3.399,

LSD (p≤0.05): C x SD 3.399, LSD (p≤0.05): T x C x SD 5.887

Legend: T= Treatment, C= cultivar, SD= Storage duration, ns= not significant

The commencement of tuber sprouting was shortly followed by dormancy end (≥80 % sprouting) at week 4, 9 and 10 for cv. Shangi, Asante and Kenya Mpya respectively. At the same point in time of dormancy end, there was 100% sprout inhibition in PBZ treated tubers in all the cultivars. There were no significant differences observed in sprouting behavior of tubers treated with ethephon and the untreated control among the cultivars throughout the experimental duration. However, pretreatment with PBZ delayed dormancy end by 4 weeks for cultivar Shangi and 3 weeks for cultivar Kenya Mpya and Asante. Cultivar Shangi exhibited short dormancy period of less than one month while cultivars Asante and Kenya Mpya had medium dormancy period of approximately 2.5 months. After sprout emergence, the number of sprouted tubers increased continuously with duration of storage irrespective of the treatment and cultivar. At the end of 13 weeks, sprouting was 100% for ethephon and control treatments irrespective of cultivar. PBZ treatment recorded 86.67%, 96.67% and 100% sprouting for cultivars Kenya Mpya, Asante and Shangi, respectively. There was no statistical significant difference observed at the end of week 13 in all the treatments and cultivars (Table 5.3).

At cold storage, sprouting was significantly ($P \leq 0.05$) influenced by the main effects of cultivar and storage duration as well as the interaction between cultivar and storage duration (Table 5.4, Appendix 11). Sprouting was not observed in any treatment until week 12 and it was first observed in cultivar Shangi tubers. Asante tubers began sprouting in week 15 irrespective of the treatment. In Kenya Mpya tubers, sproutin was delayed until week 17. Generally, sprout emergence was not delayed by any treatment and therefore; control, PBZ and ethephon treatments began sprouting at the same time. However, cultivars sprouted at different times in storage. Sprouting was complete at week 14 for all cultivar Shangi tubers, week 16 for all cultivar Asante tubers and week 18 for all cultivar Kenya Mpya tubers (Table 5.4). At the end of 18 weeks in storage, sprouting was 100% in all the treatments for cultivars Shangi and Asante while in Kenya Mpya sprouting was 93.33% in control treatment and 80% in PBZ and ethephon treatments.

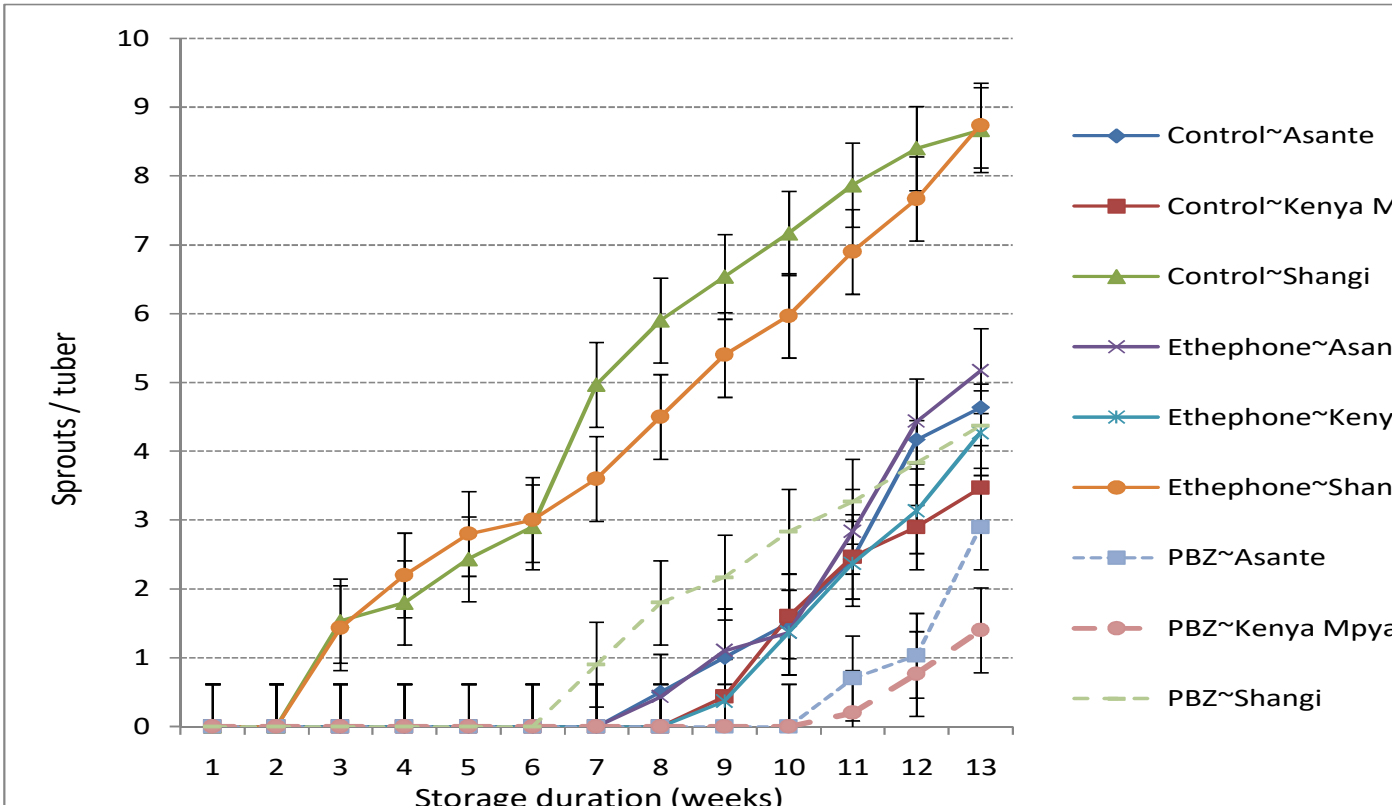
5.3.3 Number of sprouts per tuber

There was a significant ($P \leq 0.05$) interaction among treatment, cultivar and storage duration. At ambient storage, sprout development was observed at the beginning of the experiment for ethephon and control treatments on cultivar Shangi tubers and as a result, they maintained the highest number of sprouts per tuber. Ethephon and control gave the highest number of sprouts per tuber compared to the treatments that sprouted later in the experiment. Sprout development was delayed for PBZ treated tubers of cultivars Asante and Kenya Mpya until week 11, and at the end of experiment; these treatments recorded the lowest sprout number (Fig. 5.1). However, the best results were observed in cultivar Kenya Mpya tubers which recorded 1.4 sprouts per tuber while Asante tubers had 2.9 sprouts per tuber (Fig. 5.1). Cultivar Shangi tubers treated with PBZ maintained significantly high sprouts number than cultivars Asante and Kenya Mpya tubers receiving similar treatment. Generally, the number of sprouts increased with storage time. At the end of the experiment, sprout number of PBZ treated tubers was 1.4, 2.9 and 4.4 for cultivars Kenya Mpya, Asante and Shangi, respectively. On the other hand, the control treatment recorded 3.5, 4.6 and 8.7 sprouts per tuber for cultivars Kenya Mpya, Asante and Shangi, respectively. Ethephon treated tubers recorded sprouts number close to that of control treatment and it was 4.3, 5.2 and 8.7 for cultivars Kenya Mpya, Asante and Shangi respectively. Cultivar Kenya Mpya tubers sprouted toward the end of the experiment irrespective of the treatment and recorded the lowest number of sprouts compared to the other cultivars.

At cold storage, there was a significant ($P \leq 0.05$) interaction among treatments, cultivar and storage duration on the number of sprouts per tuber. Sprout emergence was first observed in cultivar Shangi tubers at week 12 in storage. Consequently, highest number of sprouts per tuber was recorded for cultivar Shangi tubers in control treatment (8.9), ethephon (8.5) and PBZ (6.6) treatments at the end of experiment. At the same point in time, the lowest number of sprouts per tuber (2.9, 2.8 and 3) was observed in cultivar Asante control, PBZ and ethephon treatments respectively (Fig 5.1).

Generally, tubers that sprouted late in storage recorded lower number of sprouts per tuber compared to tubers that sprouted earlier in the experiment and the number of sprouts per tuber increased significantly with storage duration.

(a) Ambient storage



(b) Cold storage

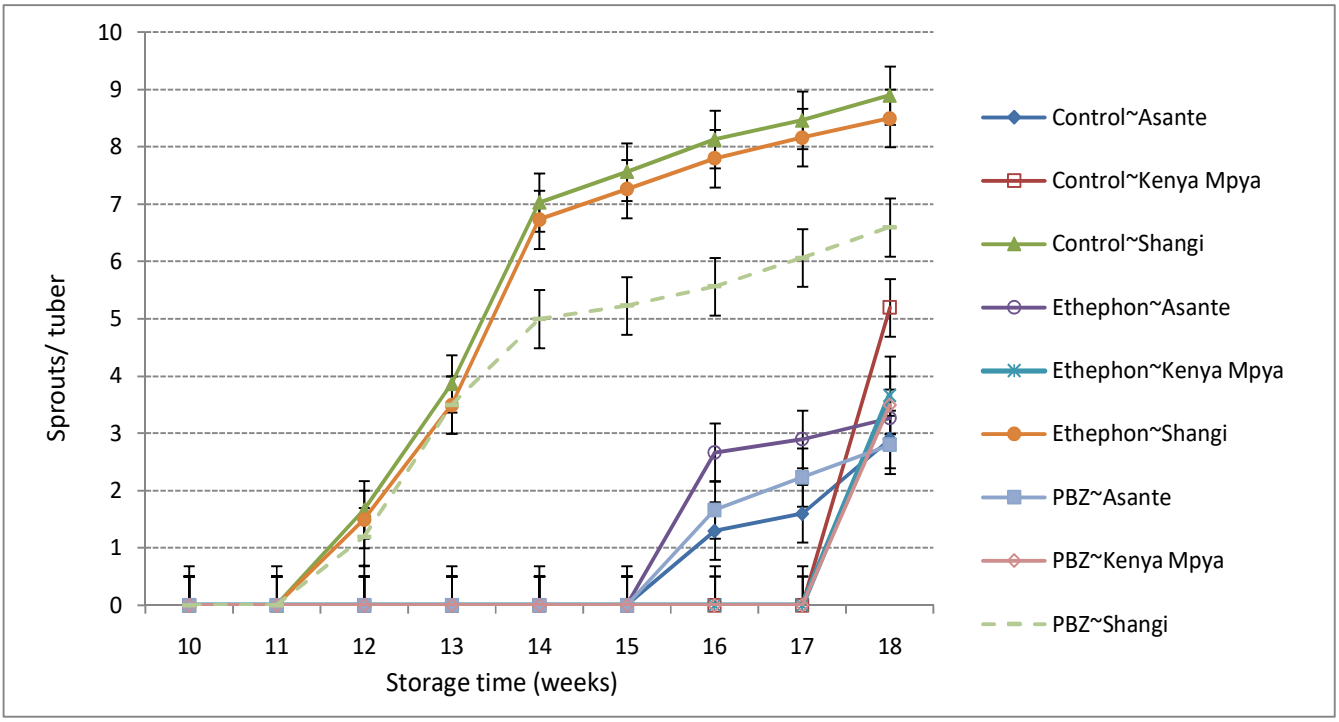


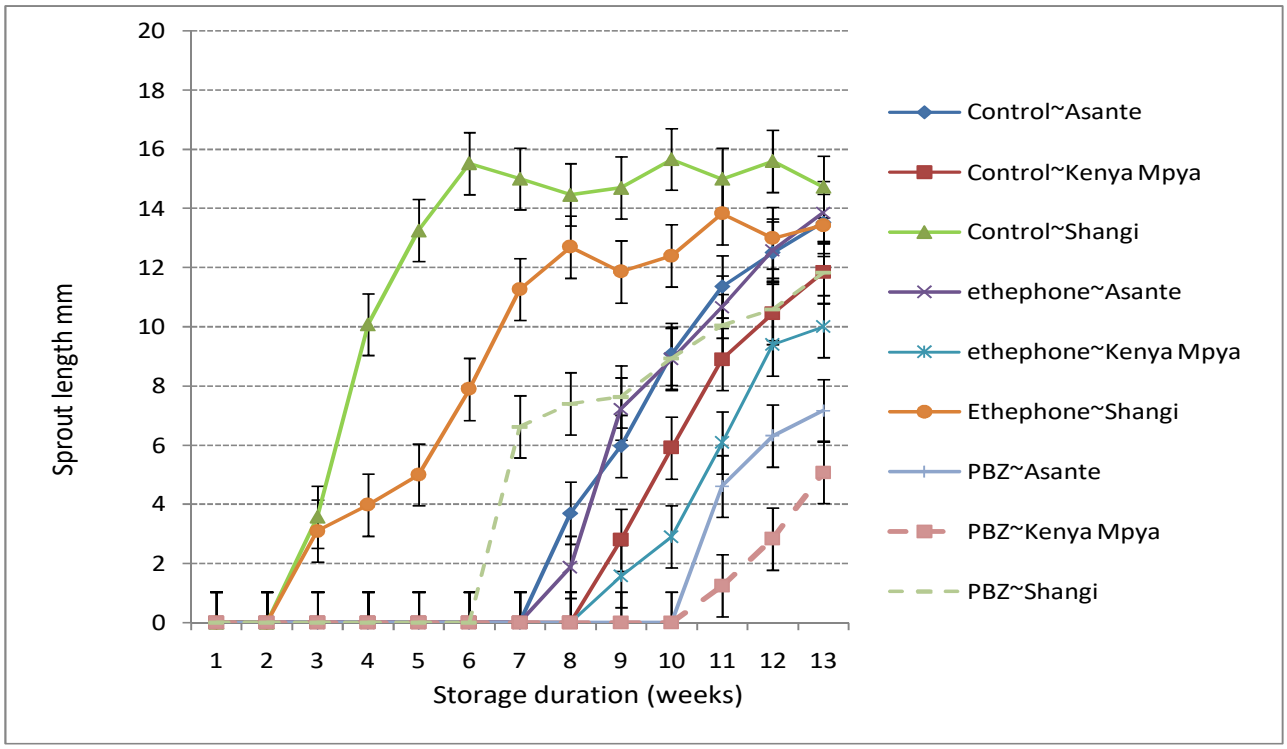
Figure 5. 1: Effect of paclobutrazol and ethephone pre- treatments on average number of sprouts per tuber of 3 potato cultivars during storage at ambient store and cold store.

5.3.4 Sprout length

Sprout length was significantly ($P \leq 0.05$) influenced by the main effects of treatment, cultivar and storage duration as well as the interactions among treatments, cultivar and duration of storage at both storage conditions. At ambient store, sprouting in ethephon and control treatments started at the beginning of the experiment for cultivar Shangi and as a result, these treatments maintained the highest sprout length compared to the treated and untreated tubers of cultivars Asante and Kenya mpya. In addition, due to early sprouting, the sprouts were frequently arrested by sprout tip necrosis (Fig 5.2). At the end of experiment, the lowest sprout length was recorded in PBZ treatment in cultivar Kenya Mpya (5.1mm), followed by cultivar Asante (7.2). Though sprout emergence in PBZ treated tubers in cultivars Asante and Kenya Mpya occurred at week 11, tubers from cultivar Kenya Mpya maintained significantly lower sprout length. Within a cultivar, sprouting differed significantly with treatments. It was lowest in PBZ treatment and highest in control and ethephon treatments. Among the cultivars, all treatments in cultivar Kenya mpya recorded significantly lower sprout length than cultivars Shangi and Asante. Generally sprout length increased in all the treatments with increased duration of storage (Fig 5.2). Control treatments had the most vigorous sprout growth. Generally, tubers that sprouted early had greater sprout length.

At cold storage, sprouting began at week 12, 15 and 17 for cultivar Shangi Asante and Kenya Mpya tubers respectively. Due to early sprouting Shangi tubers had longer sprouts for control and ethephon treatments (17mm) at the end of 18 weeks storage. PBZ treatment did not delay sprout emergence in any of the cultivars but it resulted in shorter sprouts compared to control and ethephon treatments (Fig. 5.2b). At the end of 18 week in storage, sprout lengths for PBZ treatment was 11mm, 6.9mm and 5.4mm for cultivar Shangi, Asante and Kenya Mpya tubers respectively. Cultivar Asante tubers recorded sprout length of 12.8mm and 13mm for ethephon and control treatments respectively. Sprouting was delayed until late in storage for cultivar Kenya Mpya tubers and consequently these treatments recorded the lowest sprout length (5.4-8.8mm). In each cultivar, ethephon, PBZ and control treatment sprouted at the same time. Generally, sprout length increased with storage duration.

(a) Ambient storage



(b) Cold storage

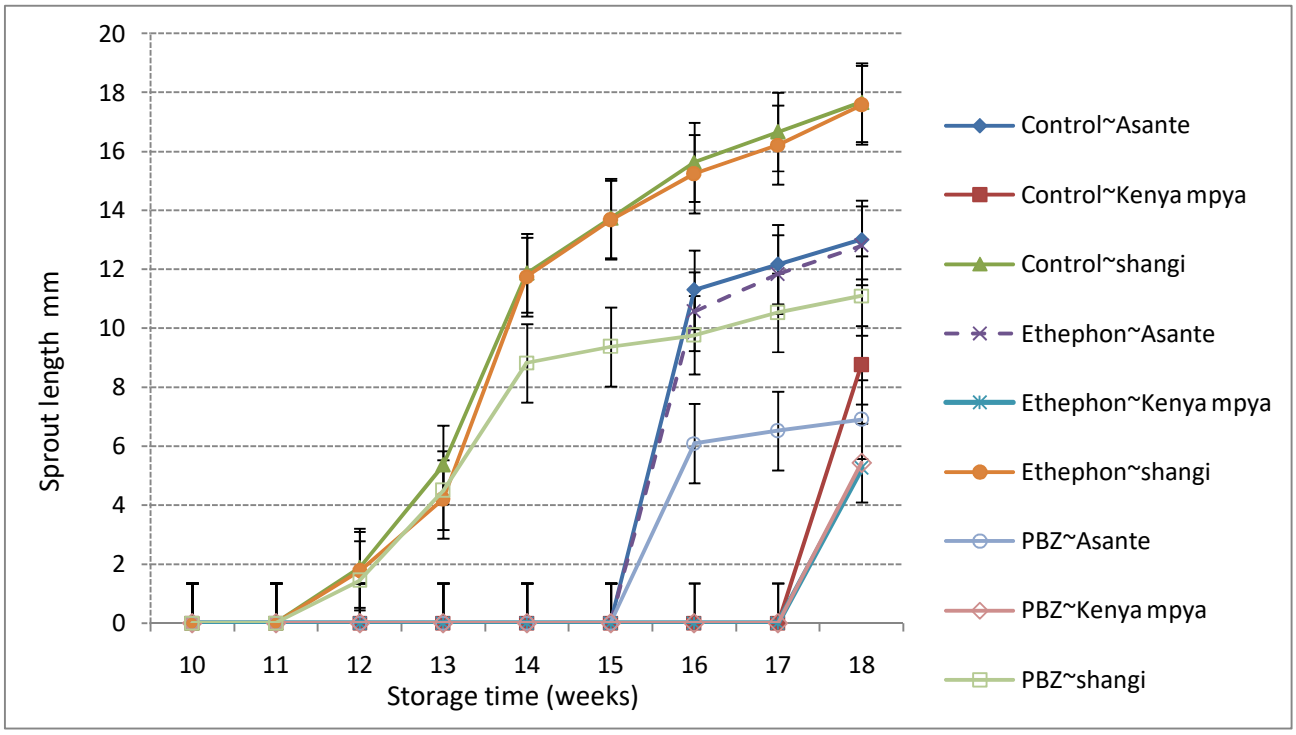


Figure 5. 2: Effect of paclobutrazol and ethephone pre- treatments on sprout length of 3 potato cultivars during storage at ambient storage and cold storage.

5.3.5 Sprout thickness

At ambient storage, sprout thickness was significantly ($P \leq 0.05$) affected by the main effects (treatments, cultivar and duration of storage) as well as all possible two-factor interactions and the three-factor-interaction. At the end of storage, thicker sprouts of 6.85mm were produced from tubers of cultivars Shangi control while thinner sprout (2.5-3.7mm) were observed in cultivar Kenya Mpya tubers irrespective of the treatment (Table 5.5). Sprout thickness increased with increased storage time irrespective of treatment and cultivar. At the end of storage, thicker sprouts were recorded in control and Ethephon treatments compared to PBZ treated tubers in all the cultivars (Table 5.5). This is probably due to the delayed sprout emergence observed in these treatments. Differences in sprout thickness among the cultivars were observed. Cultivars Shangi and Asante tubers had significantly thicker sprouts than cultivar Kenya Mpya tubers in all the treatments.

At cold storage, sprout thickness was significantly ($P \leq 0.05$) influenced by the main effects of cultivar and storage duration as well as the interaction between cultivar and storage time. Treatment alone as well as its interaction with storage time was not significant. Generally, at the end of experiment, cultivar Asante tubers gave thicker sprouts (4.5-5.06 mm) compared to Shangi (3.4-3.6mm) while Kenya Mpya tubers had thinner sprouts (2-2.8mm) (Table 5.6). Sprout thickness increased with storage duration.

Table 5. 5: Effect of treatment, cultivar and storage time on sprout thickness of 3 potato cultivars stored at ambient store with temperature of 23±2°C

Treatment	Cultivar	Sprout thickness (mm)											
		Storage time (weeks)											
		2	3	4	5	6	7	8	9	10	11	12	13
Control	Asante	0	0	0	0	0	0	1.947	3.337	4.803	5.037	5.433	5.963
Control	Kenya Mpya	0	0	0	0	0	0	0	1.45	2.913	3.487	3.79	3.727
Control	Shangi	0	1.933	2.4	3.03	3.9	4.227	4.793	5.227	5.707	6.067	6.307	6.853
Ethephon	Asante	0	0	0	0	0	0	1.42	4.857	5.52	5.643	5.723	6.21
Ethephon	Kenya Mpya	0	0	0	0	0	0	0	1.097	1.163	2.297	3.01	3.49
Ethephon	Shangi	0	2.247	2.537	2.803	3.097	3.627	4.27	4.627	5.03	5.377	5.8	6.073
Paclobutrazol	Asante	0	0	0	0	0	0	0	0	0	2.95	4.517	5.49
Paclobutrazol	Kenya Mpya	0	0	0	0	0	0	0	0	0	0.58	1.563	2.527
Paclobutrazol	Shangi	0	0	0	0	0	2.433	2.913	3.307	3.837	4.48	5.12	5.667
LSD (5%)		ns	0.1645	0.2851	0.1534	0.1447	0.2997	0.5506	0.8932	1.004	0.7897	0.8307	0.4712

LSD (p≤0.05): T 0.0825, LSD (p≤0.05): C 0.0825, LSD (p≤0.05): SD 0.1717, LSD (p≤0.05): T x C 0.1429, LSD (p≤0.05): T x SD 0.2975,

LSD (p≤0.05): C x SD 0.2975, LSD (p≤0.05): T x C x SD 0.5152

Legend: T= treatment, C= cultivar, SD= storage duration, ns=not significant

Table 5. 6: Effect of treatment, cultivar and storage time on sprout thickness of 3 potato cultivars stored at cold store with temperature of 10±2°C

Sprout thickness (mm)																	
		Storage time (weeks)															
Treatment	Cultivar	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Control	Asante	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.0033	4.2167	4.5767
Control	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.81
Control	Shangi	0	0	0	0	0	0	0	0	0	0	1.12	2.4067	3.1267	3.2467	3.4	3.48	3.5667
Ethephon	Asante	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.41	4.6933	5.0633
Ethephon	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.1567
Ethephon	Shangi	0	0	0	0	0	0	0	0	0	0	1.05	2.03	3.0633	3.1567	3.33	3.3667	3.4333
Paclobutrazol	Asante	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4.16	4.3433	4.5667
Paclobutrazol	Kenya Mpya	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.0033
Paclobutrazol	Shangi	0	0	0	0	0	0	0	0	0	0	0.9333	2.2667	3.3533	3.4233	3.53	3.5867	3.6667
LSD (5%)		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	0.1742	0.2332	0.3386	0.3458	0.5811	0.5463	0.6779

LSD (p≤0.05): T 0.03510, LSD (p≤0.05): C 0.03510, LSD (p≤0.05): SD 0.08597, LSD (p≤0.05): T x C 0.06079, LSD (p≤0.05): T x SD 0.14890

LSD (p≤0.05): C x SD 0.14890, LSD (p≤0.05): T x C x SD 0.25790

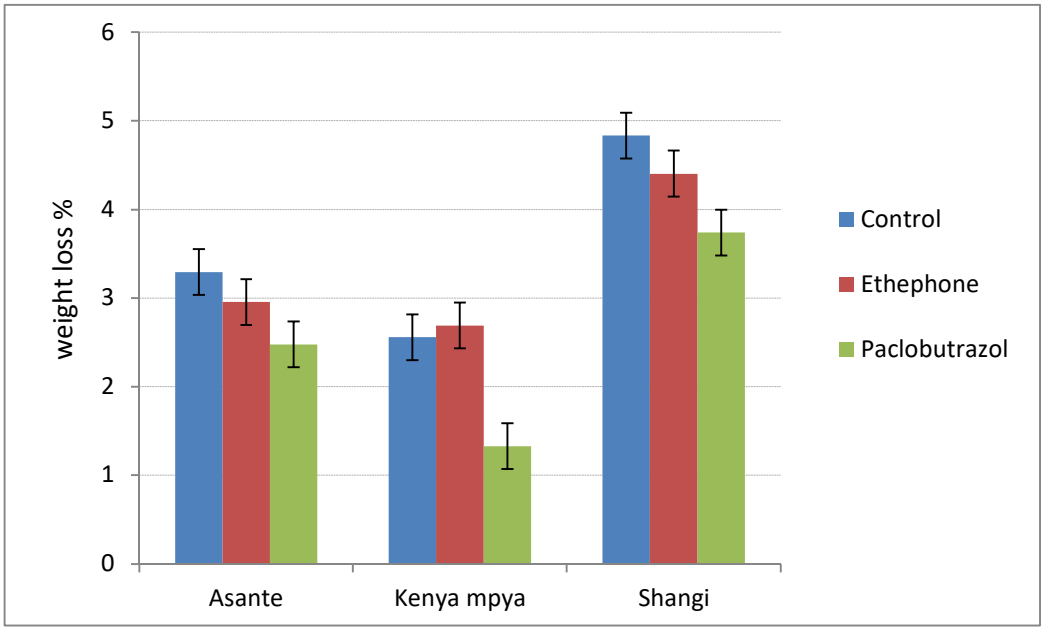
Legend: T= treatment, C =cultivar, SD= storage duration, ns= not significant

5.3.6 Weight loss

It was observed that weight loss was significantly ($P \leq 0.05$) influenced by the main factors of treatments and cultivar but the interaction between cultivar and treatment was not significant. There was no tuber decay therefore total weight loss accounted for here resulted from tuber weight loss over time probably due to metabolic processes. PBZ treated tubers lost significantly lower weight compared to ethephon and control treatments. There was no significant difference in weight loss of the control and ethephon treaments within each cultivar. However, differences among cultivars were observed. The minimum weight loss was observed in cultivar Kenya Mpya and the maximum weight loss was observed in cultivar Shangi. At the end of the experiment, PBZ treatment recorded the lowest weight loss of 1.328%, 2.477% and 3.74% for cultivars Kenya Mpya, Asante and Shangi, respectively. Ethephon treated tubers recorded 2.691%, 2.956% and 4.404% weight losses for cultivars Kenya Mpya, Asante and Shangi, respectively. Weight loss in control treatment was close to that of ethephon treated tubers and it was 2.558%, 3.295% and 4.832% for cultivars Kenya Mpya, Asante and Shangi, respectively. Weight loss was almost doubled in control treatment compared to PBZ treatment in cultivar Kenya Mpya (Fig. 5.3)

At cold store, weight loss was significantly ($P \leq 0.05$) influenced by the main effect of cultivar (Fig. 5.3). Treatments as well as the interaction between treatment and cultivar were not significant. Cultivar Shangi tubers recorded the highest weight loss (2.997- 3.175%) compared to Asante tubers (2.6-2.7%) and Kenya Mpya tubers (2-2.2%).

(a) Ambient storage



(b) Cold storage

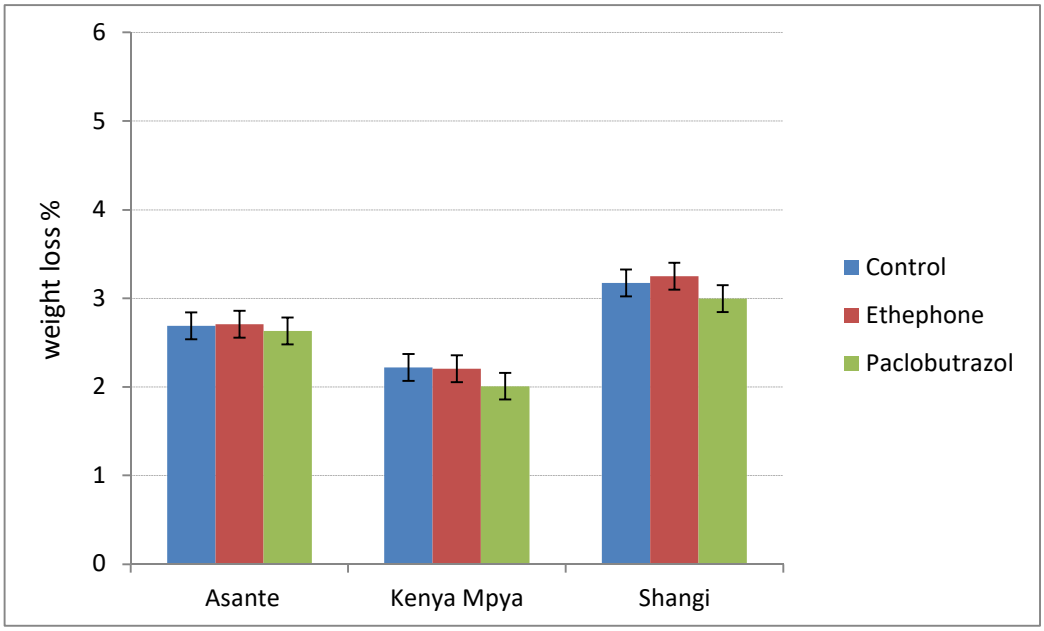


Figure 5. 3: Effect of PBZ and ethephon pretreatment on weight loss (%) of 3 potato cultivars during storage at ambient store and cold store.

5.4 DISCUSSION

Paclobutrazol is a growth retardant known to interfere with GA biosynthesis (Rademacher, 2000; Graebe, 1987; Jung et al., 1987). As an inhibitor of GA synthesis, PBZ has been shown to extend dormancy in potato tubers (Harvey et al., 1991; Bandara and Tanino, 1995). Treatment with PBZ significantly extended the tuber dormancy period by 21-31 days at ambient store. This is in agreement with results of other researchers. When potato tubers were grown under high day and night temperatures of 35^{o}C/ 20^{o}C and treated with foliar spray or soil drench at the rates of 45-90 mg a.i. PBZ plant^{-1}, dormancy was extended by approximately 30 days (Tekalign and Hammes, 2004). Paclobutrazol applied as a foliar spray to Norland potato tubers at the rate of 450 mg/L increased the dormancy period by 3 weeks (Bandara and Tanino, 1995). Treatment with PBZ at the rate of 150 mg L^{-1} prolonged the dormancy length of minitubers by 5-20% that of the control (Lim et al., 2004).

The extension of dormancy length by PBZ treatment could be attributed to inhibition of GA biosynthesis in response to PBZ treatment resulting in low GA concentration within the tubers. In addition, PBZ treatment has also been reported to reduce ABA catabolism (Ashrafuzzaman et al., 2009) that could result in high ABA levels within treated tubers. Gibberellins are considered as growth promoters involved in the termination of dormancy (Suttle, 2004; Kucera et al., 2005). Treatment of dormant tubers with GA has been reported to enhance dormancy break (Alexopoulos et al., 2008). It has been reported that ABA inhibit sprouting by hindering DNA and RNA synthesis (Suttle, 2004; Suttle and Hultstrand, 1994). Tubers from paclobutrazol treated plants showed fewer sprouts per tuber and reduced sprout growth compared to the control and ethephone treatment. This could be due to the late sprouting of PBZ treated tubers compared with ethephon and control treatment within each cultivar. However, Boldt (2008) cited that cultivars differ in their sensitivity to PBZ treatment.

Distinct differences among cultivars were exhibited with respect to sprout length, number of sprouts and sprout thickness at the end of experiment. These differences are attributable to their dormancy period and sprouting characteristics which could be influenced by their genetic makeup. At the end of experimental duration, tubers that had short dormancy period had high number of spouts per tuber, high sprout length and thicker sprouts compared to tubers that had longer dormancy period. The results of this study concludes that tubers that sprout early in storage ends up having longer sprouts that are thicker than tubers that sprout late in storage.

At cold store, the treatments were not effective in delaying sprouting and dormancy end. However, reduced temperature storage significantly extended the dormancy period irrespective of treatment. It was also observed that cultivars that showed early sprouting and shorter dormancy period at ambient store behaved similarly at reduced temperature compared to cultivars with longer dormancy period.

Ethephon treatment did not have an effect on tuber dormancy period. Sprout emergence and growth were not significantly different from the control treatment. This implies that pre-treatment with ethephon did not have a marked effect on the endogenous ethylene levels enough to have an effect on dormancy length. Given that ethephon is a highly volatile compound coupled with application in an open field, it is speculated that it was lost in the surrounding atmosphere and therefore it was not able to cause a change in the endogenous ethylene levels.

Weight loss in stored tubers results from metabolic processes of the tuber such as respiration, evaporation, moisture loss and sprouting (Wustman and Struik, 2007). The significant reduction in weight loss observed in tubers resulting from pre-harvest treatment with PBZ could be associated with late sprouting compared to ethephon and control treatments. The highest weight loss recorded in cultivar Shangi treatments could be attributable to the early sprout emergence, long sprouts and more sprouts compared to cultivar Asante and Kenya Mpya. Control and ethephon treatments exhibited the highest weight loss in each cultivar probably due to early sprouting as well. Sprouting has been reported to increase weight loss. Alexopoulos et al. (2008) reported that sprouting results in increased metabolic activity due to sprout growth leading to increased respiration and weight loss.

Sprouting causes direct weight loss due to their faster metabolic activity, high surface area and increased respiration resulting in increased starch breakdown leading to weight loss (Gautam et al., 2013; Benkeblia et al., 2008; Wustman and Struik, 2007). Additionally, the presence of sprouts increases evaporation because the epidermis of the sprouts is 100 times more permeable to water than the tuber periderm (Benkeblia et al., 2008). Lower weight loss was recorded in tubers stored at cold store than at ambient store. This could be attributed to the high temperature in the ambient store that may have caused increased respiration, sprouting and sprout growth of the tubers. The rate of respiration, sprouting and sprout growth increases when storage temperature is above $10^{o}C$ (Wustman and Struik, 2007; Wiltshire and Cobb, 1996). In line with the current results, previous research report indicated a decrease in total weight loss of potato tubers due to foliar spray treatment with PBZ (Kumar et al., 2010). Low temperature treatment in combination with pre-

treatment with PBZ has been reported to result to lower weight loss compared to untreated control (Lurie et al., 1994).

Significant differences in weight loss among the cultivars were observed. Cultivar Shangi treated and untreated tubers recorded higher weight loss than Asante and Kenya Mpya. Additionally, cultivar Kenya Mpya tubers recorded significantly lower weight loss. Pande et al. (2007) reported that tuber weight loss was cultivar dependent and the cultivars that exhibit longer dormancy with reduced sprout growth and less number of sprouts has restricted weight loss. Ezekiel et al. (2004) indicated that variations in weight loss during storage among cultivars are due to either their periderm characteristics or their sprouting behavior. The higher rates of weight loss in ethephon and control treatments probably resulted from the presence of many sprouts and high sprout length on these tubers. The reduction in weight loss observed in each cultivar could be as a result of late sprout development of PBZ treated tubers compared to control and ethephon treatments.

5.5 CONCLUSION

Pre-harvest application of Paclobutrazol resulted in prolonged dormancy period by 21-31 days when tubers were stored at ambient conditions. This treatment is beneficial for short-term storage of ware potatoes not exceeding one month. From the study, the treatments are not necessary if tubers are to be stored at reduced temperatures of less than 12^{o}C. Additionally, the treatments may not be economically beneficial for adoption as sprout suppressants in Kenya.

CHAPTER SIX: SHELF LIFE AND QUALITY OF WARE POTATO TUBERS *(Solanum tuberosum* L.*)* AS INFLUENCED BY PACKAGING MATERIAL DURING STORAGE

Abstract

Post harvest losses due to use of inappropriate packaging materials, poor handling and storage management, limited information regarding the maintenance of quality and safety of perishables at the retailer level has been estimated to be 24.4% of post harvest losses. Losses occur due to sprouting, weight loss, decay, greening incidences and wilting. The effect of five packaging materials; high density polyethylene bags (HDPE) and low density polyethylene bags (LDPE), nylon gunny sacks, khaki bags and net bags on quality of three potato cultivars was evaluated. The polyethylene bags used were both perforated and non-perforated. Quality and storage-life was determined through data collected on sprouting, weight loss rates, greening and rotting incidences. Weight loss, sprouting, tuber greening and tuber decay were significantly ($P \leq 0.05$) influenced by the interaction effect of the packaging material, cultivar and duration of storage. Generally, packaging significantly reduced weight loss, rate of tuber greening but increased the rate of sprouting and decay incidences. Non-perforated PE bags were the most effective in reducing weight loss; leading to weight loss of between 0.7% to 0.9% after 32 days in storage while unpackaged tubers (control) had the highest weight loss of 10.75%, 11.38% and 11.58% for cultivars Asante, shangi and Kenya Mpya respectively. Kenya Mpya had the highest weight loss. Tuber decay was highest (60-66%) in tubers packed in non-perforated PE bags. Rotting was not observed in tubers packaged in perforated LDPE bag, nylon gunny sack, net bags and control. Greening was faster in non-packaged tubers recording 55-100% after 2 weeks in storage. Cultivar Kenya Mpya was more susceptible to greening than Shangi and Asante and had 100% tubers green within 1 week. Sprouting was complete by week 3 in all the tubers packaged in non-perforated HDPE bags irrespective of cultivar. Sprout length and sprout thickness were high in tubers packaged in non-perforated HDPE bags. Sprouting %, sprout length, number of sprouts and sprout thickness increased with storage time. However, sprout length in non-perforated HDPE bag was frequently arrested by apical meristem necrosis in all the cultivars. Although the non-perforated HDPE bag packaging prolonged the shelf life in terms of reducing weight loss and tuber greening incidences compared to unpackaged control, their positive effect was neutralized by the high incidence of rotting evident and premature dormancy end within 3 weeks of storage. In general, the study indicated that the interaction between cultivars, packaging and storage period affected shelf

life of ware potatoes. Low density black PE bags emerged as the best method for ware potato packaging due to low sprouting, reduced weight loss, low rate of tuber greening and reduced rate of tuber decay

Key words: sprouting, packaging, weight loss, decay, greening

6.1 Introduction

Potato (*Solanum tuberosum* L.) is currently the second most important food crop in Kenya worth KSH 50 billion (NPCK, 2015). The crop is grown by over 800,000 farmers majority being small holders (NPCK, 2015). The potato industry plays a major role in the Kenyan economy as it employs about 2.5 million people directly and indirectly (Abong and Kabira, 2013). The Kenyan Government has recognised potato's critical role in alleviating food shortages and it is set to help the country realize the set objectives for vision 2030, Sustainable Development Goals and the Agricultural Sector Development Strategy (NPCK, 2015).

Potato production is slowly declining due to the issues of climate change coupled with overreliance on rainfall hence threatening our food security (Mwaura, 2009). The problem is further aggravated by high post harvest losses. Physical and quality losses occur between harvest and at consumer level and it varies greatly along the value chain. Causes of ware potato storage losses include premature and excessive sprouting, tuber greening, tuber decay, transpiration and respiration; which are physiological activities dependent on the storage conditions majorly temperature and relative humidity ((Osunde and Orhevba, 2009)). These losses are attributed to use of inappropriate packaging materials, poor storage management, poor handling, and generally limited information regarding the needs for maintaining quality and safety of perishables at the producer, wholesaler, and retailer levels (Kader, 2004). A survey conducted in Kenya outlined the post harvest losses as follows: at the farm level (includes poor harvesting and storage) 12.8 %, in open market 24.4%, at processing level 12% and 25% in supermarkets (Kaguongo et al., 2014). On average, 19 % of total production per hectare which represents about KES 42,824 is lost every season (Kaguongo et al., 2014).)

During storage, quality of harvested produce is governed by temperature, relative humidity, air velocity, and atmospheric composition (concentrations of oxygen, carbon dioxide, and ethylene

(Kader, 2004). Physical and quality losses are due to sprouting, weight loss, decay, greening incidences and wilting. Sprouting leads to weight loss, loss of marketable tubers and reduces the nutritional and processing quality of tubers (Suttle, 2003). Tuber greening occurs when tubers are exposed for an extended period to intense light causing chlorophyll formation in leucoplasts which then causes tuber tissues to turn green (Hooker, 1981).As a results, the affected tubers are not marketable for food. Increased moisture loss and respiration results in weight loss during storage. Ware potato quality is determined by the visual appearance which includes absence of visible sprouts, decay, and absence of greening as well as firmness (Rezaee et al., 2011; Booth et al., 1972; Pinhero et al., 2009).

Minimizing storage losses and extending shelf life of tubers is very important in this era of food security concerns. The technologies used to reduce post harvest deterioration in vegetables are low temperature storage, modified atmosphere packaging and controlled atmosphere packaging among others. Modified atmosphere packaging has been used extensively in fruits and vegetables. This technique involves modifying the atmosphere to create low O_2 and high CO_2 levels within the package atmosphere with the aim of extending shelf life (Beaudry, 2000; Mangaraj and Mahajan, 2009). In addition to atmosphere modification, MAP greatly improves moisture retention (Ben-Yehoshua et al., 1983; Yumbya et al., 2014). Modified atmospheres is generated through the natural process of respiration by the enclosed product which reduces oxygen concentration and increases carbon dioxide concentration under restricted gas exchange through the film barrier (Beaudry, 2000). The effect of these changes in gas composition varies with commodity but it generally reduces respiration rate and reduce susceptibility to pathogens (Gorris and Peppelenbos, 1992; Kader et al., 1989). MAP also causes a water saturated atmosphere within the package which reduces water loss and shrinkage (Ben-Yehoshua et al., 1983). On the other hand, conditions unfavorable to a given commodity can induce physiological breakdown rendering it more susceptible to pathogens (Kader et al., 1989). Film packaging creates MA conditions that creates a high relative humidity, excludes light when needed and prevent spread of decay from one unit to another (Kader et al., 1989). MAP technique has been used as an alternative to refrigeration for preservation of fresh produce. This method is inexpensive and readily available. MAP is an increasingly important food preservation technology being applied on several vegetable. Because of such beneficial effects MAP can be of interest in preserving ware potato quality.

Over the years in Kenya, ware potatoes have been packaged in polyethylene bags, nylon gunny sacks, khaki bags and net bags in the retail market. The objective of this research was to investigate the effect of packaging materials (high and low density polyethylene bags; perforated and non-perforated, nylon gunny sacks, khaki bags and net bags) on the quality of ware potato tubers during short term storage with the aim of improving the availability of data to minimise the postharvest losses.

6.2 MATERIALS AND METHOD

6.2.1 Plant material

Three potato cultivars were used in this study, Shangi which is a short dormancy variety (30 days), Asante and Kenya mpya both medium dormancy varieties (60 days). These potatoes were grown at the University of Nairobi kabete field station farm between April- July 2013 (season 1) and between October- January 2013 (season 2). Standard agronomic practices recommended for potatoes including ridging, pest control, fertilization and weeding were utilized. Freshly harvested potato tubers free of any evident disease and without any signs of sprouting were selected for packaging.

6.2.2 Types of packaging material used

Bags made of seven different types of packaging materials were used in the experiment: Black non-perforated and perforated low density polyethylene bag (LDPE), Clear/ transparent non-perforated and perforated high density polyethylene bag (HDPE), Khaki bag, Nylon gunny sack, Net/ mesh bag and open trays as control. The PE bags were perforated with 20 holes each (diameter 3 mm).

The packaged tubers were randomly distributed on benches in the laboratory. The benches were used as the blocking factor. The experimental design comprised of 3 x 8 factorial combinations of treatments laid out in a completely randomized block design (CRBD) replicated three times. Each package had 20 tubers. The storage temperature at the laboratory was 23±2°C.

6.2.3 Data collection

During data collection, the tubers were removed from the packages for approximately 10 minutes per sample.

i. Weight loss

Weight measurements were done at the beginning of the experiment and after every 3 days thereafter to determine the weight loss trend over 32 days of storage.

ii. Cumulative weight loss

Cumulative weight loss was calculated as the change between the initial weight at the beginning of the experiment and the final weight measurements at the end of the experiment (32 days). The change in weight was expressed as a percentage of the initial weight.

iii. Tuber greening %

Tuber greening was evaluated visually and the number of green tubers within each package recorded. Any tuber showing signs of a green coloration was considered to have greened. Greening percentage was calculated as the percentage of all the greened tubers in the sample then averaged on per sample basis

iv. Tuber decay

Evaluations on tuber decay were made visually by observing each tuber for any sign of decay. The number of rotten tubers within a sample was recorded for 5 weeks. Tuber decay was expressed as a percentage of all the rotten tubers in the sample then averaged on per sample basis

v. Sprouting %

Sprouting percentage was calculated as the percentage of all the sprouted tubers in the sample then averaged on per sample basis. This was done weekly. A tuber was considered sprouted when it had at least one visible sprout of at least 3mm length.

vi. Days to dormancy end

Dormancy period was recorded as number of days since harvesting to when 80% of tubers had visible sprouts of 3mm in length (i.e. when 16 out of 20 tubers sprouted in each experimental unit). Tubers were checked at 7 day interval until one of the tuber produced the first sprout in each treatment, then after every three days to accurately record the dormancy period.

vii. Number of sprouts per tuber

The numbers of sprouts per tuber were counted and the average was calculated on per tuber basis. Data was collected weekly.

viii. Sprout length

It was determined by measuring the length of the longest sprout in every sprouted tuber per sample. Measurements were done from the base of the sprout to the tip and data recorded in mm. The data was averaged on per tuber basis. Data was recorded weekly.

ix. Sprout thickness

Sprout thickness was evaluated based on the thickness of the base of the longest sprout in every sprouted tuber per sample. The data was collected weekly and averaged on per tuber basis.

6.3 Statistical analysis

Analysis of variance was performed on the data using Genstat statistical program (Genstat, 2010). Mean differences among the treatments were separated by Tukey's least significant difference procedure at 5% level of significance.

6.4 RESULTS

6.4.1Weight loss trend and cumulative weight loss

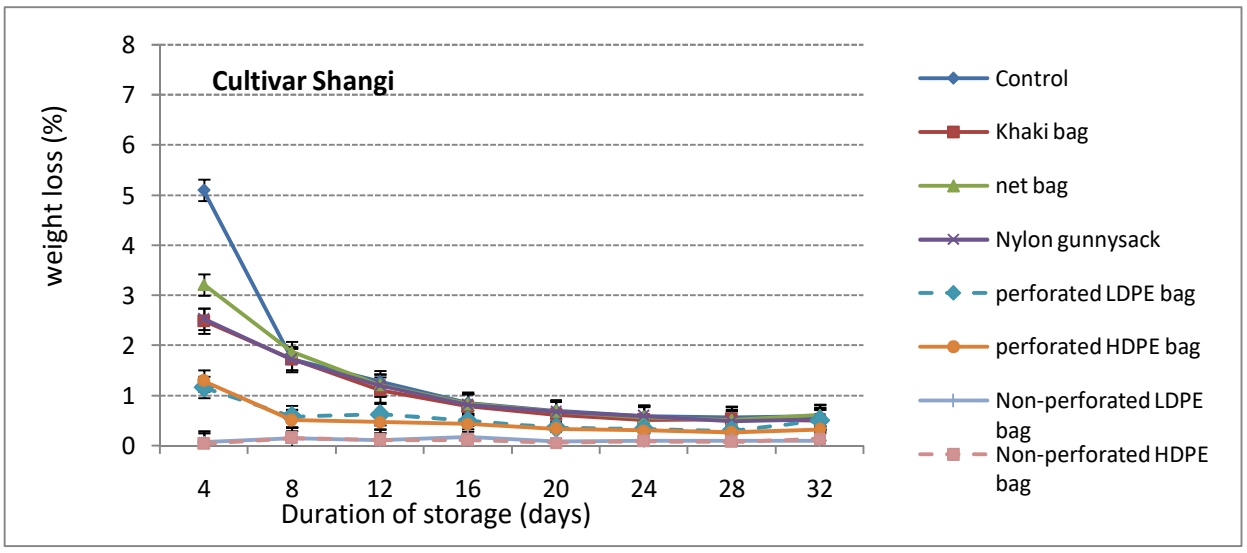
The analysis of variance revealed that the main effect of packaging material, cultivar and storage duration as well as all possible two-factor interactions and the three-factor-interaction had highly significant ($P < 0.001$) effect on weight loss (Appendix 1). The least cumulative weight loss over 32 days in storage was observed in tubers packaged in non-perforated HDPE and LDPE bags for all the cultivars with no significant difference between the HDPE and LDPE bags (Table 6.1). At the end of storage, % weight loss was 0.72, 0.75 and 0.87 for cultivars Shangi, Asante and Kenya Mpya, respectively packaged in non-perforated HDPE bags. High weight loss was observed with the unpackaged tubers recording 11.38%, 10.745% and 11.58% weight loss for cultivars Shangi, Asante and Kenya Mpya, respectively. This was approximately 15.8, 14.3 and 13 times more weight lost when compared to that of non-perforated HDPE bags. Tubers packaged in non-perforated LDPE bags recorded 0.84%, 0.89% and 0.91% weight loss for cultivars Shangi, Asante and Kenya Mpya, respectively. Net bags packaging recorded significantly high weight loss than the rest of packaging materials resulting in 9.12%, 10.34 and 10.72% weight loss for cultivars Shangi, Asante and Kenya Mpya, respectively (Table 6.1). However, it was lower than that of non-packaged tubers. When the PE bags were perforated, weight loss was significantly higher than the non-perforated PE bags. Perforated HDPE bags recorded 3.81%, 3.76% and 3.92% for cultivars Shangi, Asante and Kenya Mpya tubers, respectively. On the other hand, % weight loss was 4.27%, 3.28% and 4% in cultivars Shangi, Asante and Kenya Mpya tubers, respectively packaged in perforated LDPE bags. Though not statistically significant, weight loss of cultivars Shangi and Kenya Mpya tubers packaged in LDPE bag was higher than that of tubers packaged in HDPE bags. Nylon gunny sacks and khaki bags packaging had moderate effect on weight loss. At the end of storage, tubers packaged in nylon gunny sack recorded 8.22%, 6.53% and 7.45% weight loss for cultivars Shangi, Asante and Kenya Mpya, respectively. Khaki bag recorded 7.97%, 8.35% and 9.98% weight loss for cultivars Shangi, Asante and Kenya Mpya tubers, respectively. Generally weight loss differed significantly among the cultivars with Kenya mpya having the highest total weight loss compared to Asante in all of the packages tested (Table 6.1).

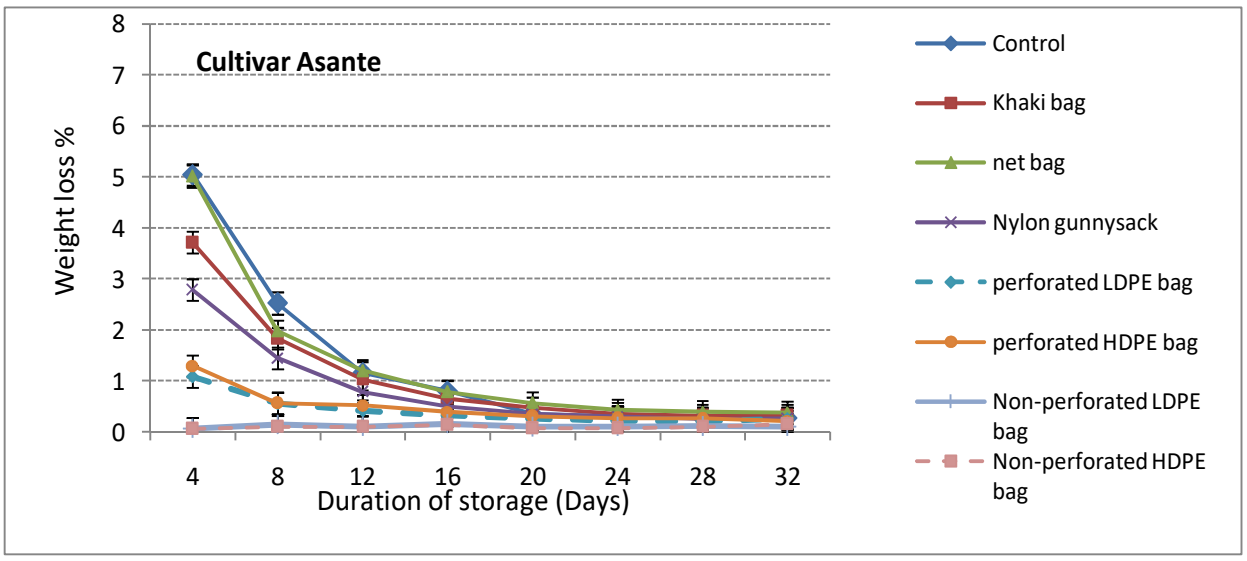
Table 6. 1: Effect of packaging material on cumulative % weight loss of ware potato tubers after 32 days in Kenya

	Weight loss (%)		
	Cultivars		
Type of Packaging material	Asante	Shangi	Kenya Mpya
Control (trays)	10.745^{fg}	11.377^{g}	11.58^{g}
Khaki bag	8.349^{cde}	7.976^{cd}	9.983^{efg}
Net bag	10.34^{fg}	9.128^{def}	10.72^{fg}
Nylon gunnysack	6.534^{c}	8.224^{cde}	7.45^{cd}
Perforated LDPE bag	3.284^{b}	4.265^{b}	4.015^{b}
Perforated HDPE bag	3.758^{b}	3.813^{b}	3.917^{b}
Non-perforated LDPE bag	0.889^{a}	0.837^{a}	0.913^{a}
Non-perforated HDPE bag	0.753^{a}	0.719^{a}	0.869^{a}

Values followed with different letters in rows and columns are significantly different according to Tukey's protected least significant difference test (P<0.05)

Weight loss decreased with storage time. The tubers stored in non-perforated PE bags experienced significantly low rate of weight loss trends and generally maintained the lowest weight loss trend among the packaging materials throughout the experimental duration (Fig 6.1). The rate of weight loss between non-perforated HDPE bag and non-perforated LDPE bags was similar (Fig 6.1). Weight losses during the initial stages of storage were high across all the treatments but unpackaged tubers recorded the most weight loss during the first 8 days in storage. Generally, tubers continuously lost weight in storage across all the treatment combinations but it was highest for the first 12 days of storage (Fig 6.1). Towards the end of experimental duration, the rate of weight loss trend became similarly low and tubers packaged in khaki bags, net bags, nylon gunny sack and control displayed somewhat similar weight loss trend (Fig. 6.1) but it was still significantly higher than that of tubers packaged in PE bags. Despite heavy sprouting of tubers packaged in non-perforated PE bags, it was also observed that tubers preserved their initial firmness for a long period of storage, while non-packaged tubers significantly shriveled.





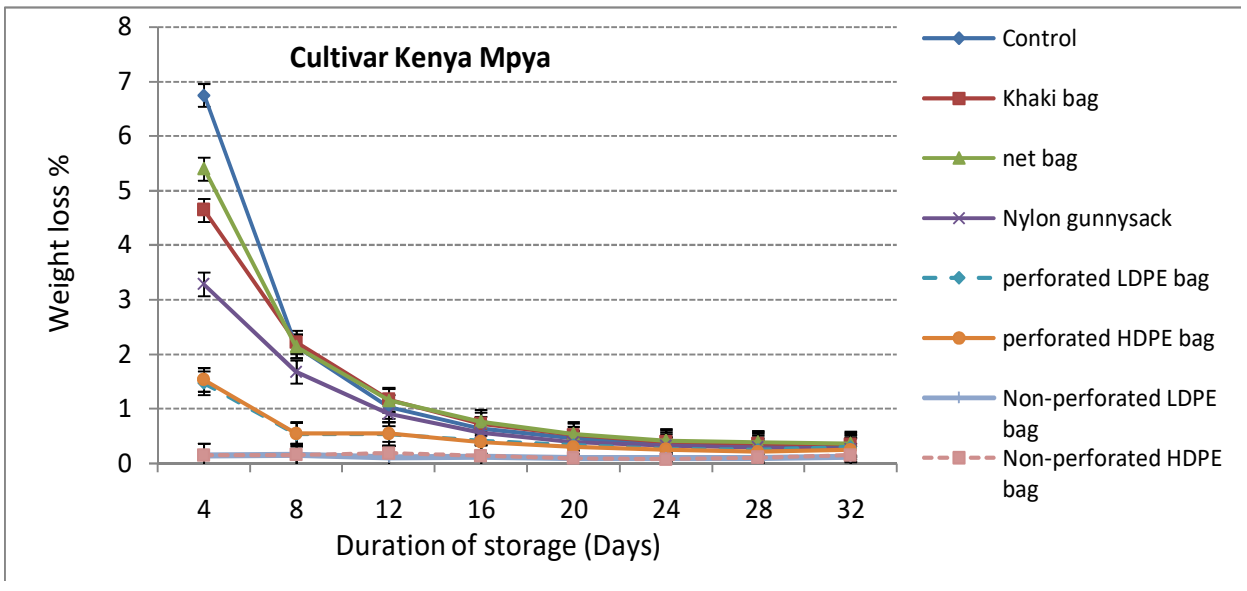


Figure 6. 1: Effect of packaging material on weight loss trend of ware potato tubers of 3 cultivars stored for 32 days under ambient temperature (23±2°C)

Considering weight loss alone, the potential economic life of ware potato was maintained by PE bags packaging as compared to net bags, nylon gunnysac, khaki bag and the trays.

6.4.2 Greening incidence

The main effects of packaging material, cultivar and duration of storage as well as all possible interactions exhibited significant ($P<0.05$) influence on tuber greening (Appendix 2). Generally, packaging reduced the rate at which greening of tubers occurred. The most effective package to reduce tuber greening was perforated and non-perforated black LDPE bags. In five weeks of storage, tubers packaged in black LDPE bags had no visible green coloration. At the same point in time, greening was 100% in unpackaged tubers and tubers packaged in net bags. Khaki bags significantly lowered the number of green tubers and at the end of storage, greening was 26.7%, 43.3% and 50% for cultivars Asante, Shangi and Kenya Mpya tubers, respectively. At the end of five weeks storage, 100% greening was observed for cultivar Shangi and Kenya Mpya tubers, packaged in nylon gunny sacks, net bags, perforated clear HDPE bags and the control. The unpackaged tubers began forming visible green coloration within 7 days of the experiment. The most susceptible cultivar was Kenya Mpya tubers recording 100% greening in 7 days. Generally, the number of tuber green tubers increased with storage time. Asante tubers recorded significantly lower greening incidences in most packaging materials tested while Kenya Mpya tubers recorded the highest (Table 6.2).

Table 6. 2: Effect of packaging on tuber greening (%) for cultivars Shangi, Asante and Kenya Mpya tubers during 5 weeks storage under ambient conditions in Kenya

		Green tubers (%)				
Package type	Cultivar	1	2	3	4	5
Unpackaged (control)	Asante	36.7	55	78.3	100	100
	Kenya Mpya	100	100	100	100	100
	Shangi	51.7	100	100	100	100
Khaki bag	Asante	0	1.67	6.67	15	26.7
	Kenya Mpya	3.33	23. 3	33.3	38.3	50
	Shangi	0	5	5	16.7	43.3
Net bag	Asante	15	40	53.3	91. 7	100
	Kenya Mpya	50	66.7	100	100	100
	Shangi	38.3	55	100	100	100
Non-perforated black LDPE	Asante	0	0	0	0	0
	Kenya Mpya	0	0	0	0	0
	Shangi	0	0	0	0	0
Non-perforated clear HDPE	Asante	0	0	0	5	20
	Kenya Mpya	0	6.67	16.7	43.3	60
	Shangi	0	6.67	20	30	46.7
Nylon gunnysack	Asante	1.67	20	33.3	48.3	61.7
	Kenya Mpya	43.3	68.3	100	100	100
	Shangi	26.7	50	70	75	100
Perforated black LDPE bag	Asante	0	0	0	0	0
	Kenya Mpya	0	0	0	0	0
	Shangi	0	0	0	0	0
Perforated clear HDPE bag	Asante	3.33	15	28.3	41.7	46.7
	Kenya Mpya	56.7	70	100	100	100
	Shangi	25	45	100	100	100
LSD (5%)		9.145	13.504	14.28	12.645	10.741
LSD ($p \leq 0.05$): C	1.879					
LSD ($p \leq 0.05$): P	3.069					
LSD ($p \leq 0.05$): SD	2.426					
LSD ($p \leq 0.05$): C X P	5.315					
LSD ($p \leq 0.05$): C X SD	4.202					
LSD ($p \leq 0.05$): P X SD	6.862					
LSD ($p \leq 0.05$): C X P X SD	11.885					

Legend: HDPE= High density polyethylene bag, LDPE=Low density polyethylene bag, C=cultivar, P= Package type, SD= storage duration

6.4.3 Decay incidence

Tuber decay was significantly (P≤0.05) influenced by the main effect of packaging material. However, the main effect of cultivar as well as the interaction between cultivar and packaging had no significant effect on tuber decay (Table 6.3, Appendix 3). Rotting was not observed in tubers packaged in perforated LDPE bags, nylon gunny sacks, net bags and control in open trays. During the 5 weeks of storage, decay was greatest in tubers packaged in non-perforated HDPE bags with losses being as high as 63.7% (Table 6.3). Tubers packaged in non-perforated LDPE bags recorded significantly high % of rotten tubers which was 15.56. Rotting of tubers packaged in khaki bags and perforated HDPE bags were significantly low (less than 5%). Statistically significant difference in decay among tubers packaged in khaki bags perforated HDPE bags with those that did not have decay incidences were not observed in this experiment.

Table 6. 3: Effect of ware potato packaging on tuber decay (%) during 5 weeks in storage under ambient storage in Kenya.

Type of package	Decay (%)
Control	0[a]
Net bag	0[a]
Nylon gunny sack	0[a]
Perforated black LDPE bag	0[a]
Perforated clear HDPE bag	0.76[a]
Khaki bag	4.44[a]
Non-perforated black LDPE bag	15.56[b]
Non-perforated clear HDPE bag	63.7[c]

Different letters in columns in each character indicate significant differences according to Tukey's protected least significant difference test (*P*=0.05)

6.4.4 Sprouting percentage and dormancy period

Sprouting percentage was significantly (P ≤ 0.05*)* influenced by the main effects of package type, storage duration and cultivar as well as all the interactions (Table 6.4). Sprouting of

ware potatoes in all cultivars commenced in the second week of storage for tubers packaged in non-perforated HDPE bags and it was complete by the end of week 2 for cultivar Shangi tubers (Table 6.4). Asante and Shangi cultivars had 100% tubers sprouted at the end of week 3 compared to 91% for Kenya Mpya tubers. Cultivar Kenya Mpya tubers attained 100% sprouting at week 4. Statistically significant differences in sprouting % among tubers of the three cultivars packaged in non-perforated HDPE bags were observed in week 2, thereafter, differences among cultivars were not observed (Table 6.4). Generally, sprouting was observed earlier in cultivar Shangi tubers in all the packages tested compared to Asante and Kenya Mpya tubers. Tubers packaged in non-perforated LDPE bags had over 80% tubers sprouted by weeks 4, 8 and 10 for cultivars Shangi, Asante and Kenya Mpya tubers respectively. By the end of week 5 in storage, cultivar Shangi tubers packaged in khaki bags, net bags, nylon gunnysack bags, perforated PE bags and the unpackaged control tubers had began sprouting. At the 6^{th} week, over 80% Shangi tubers had sprouted. In cultivar Shangi, there were no significant differences observed in tubers packaged in khaki bags, net bags, perforated PE bags, nylon gunnysacks and unpackaged tubers throughout the experimental duration. Sprouting of cultivar Asante and Kenya Mpya tubers packaged in khaki bags, net bags, nylon gunnysack bags, perforated PE bags and the unpackaged control tubers commenced at week 10. Tubers packaged in perforated PE bags, net bags, nylon gunnysack bags and the unpackaged tubers of cultivar Asante and Kenya Mpya were the last to attain 80% sprouting. Generally, % number of sprouted tubers of all the cultivars increased with increased storage duration. At the end of week 12, there were no significant differences in sprouting percentage among the packages as well among cultivars.

Table 6. 4: Effect of package type, cultivar and duration of storage on sprouting (%) of tubers stored for 12 weeks under ambient conditions in Kenya

		Sprouting (%)											
		Storage duration (Weeks)											
Package type	Cultivar	1	2	3	4	5	6	7	8	9	10	11	12
Unpackaged (control)	Asante	0	0	0	0	0	0	0	0	0	66.7	77.8	91.1
	Kenya Mpya	0	0	0	0	0	0	0	0	0	86.7	95.6	95.6
	Shangi	0	0	0	0	68.89	84.4	91.1	100	100	100	100	100
Khaki bag	Asante	0	0	0	0	0	0	0	0	0	60	68.9	100
	Kenya Mpya	0	0	0	0	0	0	0	0	0	82.2	97.8	100
	Shangi	0	0	0	0	68.89	91.1	97.8	100	100	100	100	100
Net Bag	Asante	0	0	0	0	0	0	0	0	0	75.6	80	97.8
	Kenya Mpya	0	0	0	0	0	0	0	0	0	75.6	88.9	93.3
	Shangi	0	0	0	0	82.2	86.7	93.3	100	100	100	100	100
Nylon gunny sac	Asante	0	0	0	0	0	0	0	0	0	46.7	71.1	93.3
	Kenya Mpya	0	0	0	0	0	0	0	0	0	42.2	66.7	84.4
	Shangi	0	0	0	0	82.2	88.9	93.3	100	100	100	100	100
Perforated LDPE bag	Asante	0	0	0	0	0	0	0	0	0	35.6	57.8	97.8
	Kenya Mpya	0	0	0	0	0	0	0	0	0	44.44	57.8	80
	Shangi	0	0	0	0	82.2	93.3	100	100	100	100	100	100
Perforated HDPE bag	Asante	0	0	0	0	0	0	0	0	0	20	48.9	80
	Kenya Mpya	0	0	0	0	0	0	0	0	0	35.6	60	80
	Shangi	0	0	0	0	86.7	91.1	100	100	100	100	100	100
Non-perforated LDPE	Asante	0	0	0	0	0	0	0	86.7	91.1	95.6	97.8	100
	Kenya Mpya	0	0	0	0	0	0	0	0	73.3	84.4	84.4	88.9
	Shangi	0	0	24.4	82.2	100	100	100	100	100	100	100	100
Non-perforated HDPE	Asante	0	55.56	100	100	100	100	100	100	100	100	100	100
	Kenya Mpya	0	28.89	91.11	100	100	100	100	100	100	100	100	100
	Shangi	0	86.67	100	100	100	100	100	100	100	100	100	100
LSD (5%)		ns	7.486	8.531	1.2913	10.611	5.930	3.602	4.473	5.667	17.47	16.44	8.22

LSD (p≤0.05): P 1.473, LSD (p≤0.05): C 0.902, LSD (p≤0.05): SD 1.804, LSD (p≤0.05): P x C 2.551, LSD (p≤0.05): P x SD 5.102, LSD (p≤0.05): C x SD 3.124, LSD (p≤0.05): P x C x SD 8.837

Legend: HDPE= High density polyethylene bag, LDPE=Low density polyethylene bag, C=cultivar, P= Package type, SD= storage duration, ns= not significant

Dormancy duration

There was significant (P≤0.05) interaction between package type and cultivar. The shortest dormancy period (10 days) was recorded for the cultivar Shangi tubers packaged in non-perforated HDPE bags (Table 6.5). The dormancy period for cultivars Asante and Kenya Mpya was significantly reduced to 17 and 19 days respectively when tubers were packaged in non-perforated HDPE bags. The longest dormancy period of 74-84 days was recorded for cultivar asante and Kenya Mpya tubers packaged in perforated HDPE bags, trays, perforated LDPE bags, nylon gunnysack, net bag and khaki bags (Table 6.5). Generally, tubers of cultivar Shangi had the shortest dormancy period irrespective of the type of package. Kenya Mpya, tubers packaged in perforated LDPE, perforated HDPE and nylon gunnysack had statistically longer dormancy period than those packaged in trays, khaki bag, net bag and non-perforated black LDPE bag. It is worth noting that tubers of cultivar Asante and Kenya Mpya packaged in nylon gunnysacks, perforated HDPE and perforated LDPE bags had longer dormancy period than that of unpackaged control tubers.

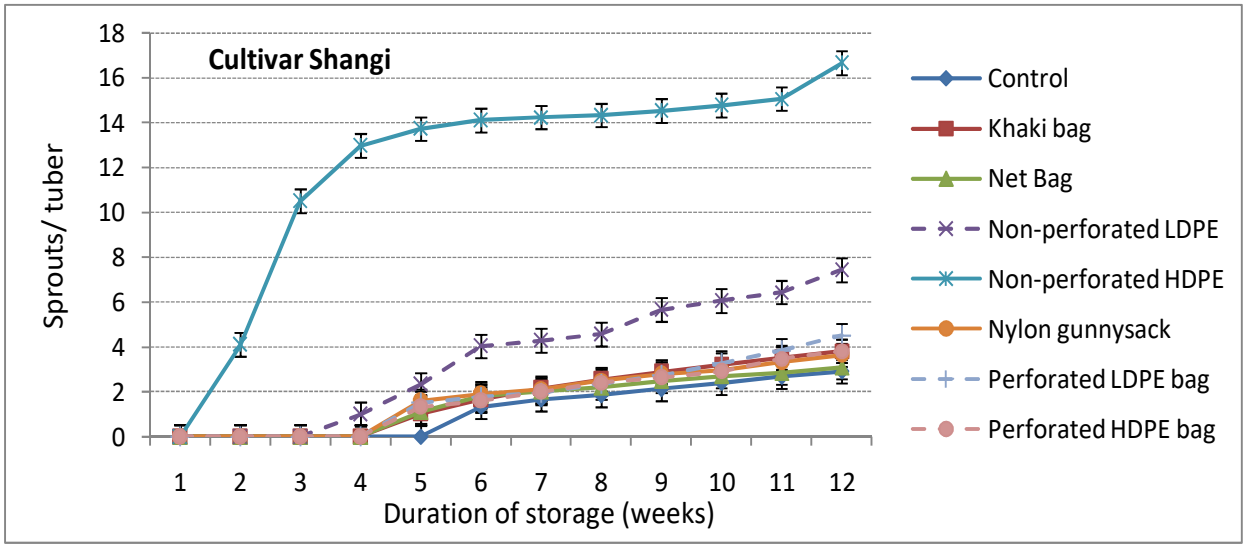
Table 6. 5: Effect of packaging and cultivars on dormancy duration

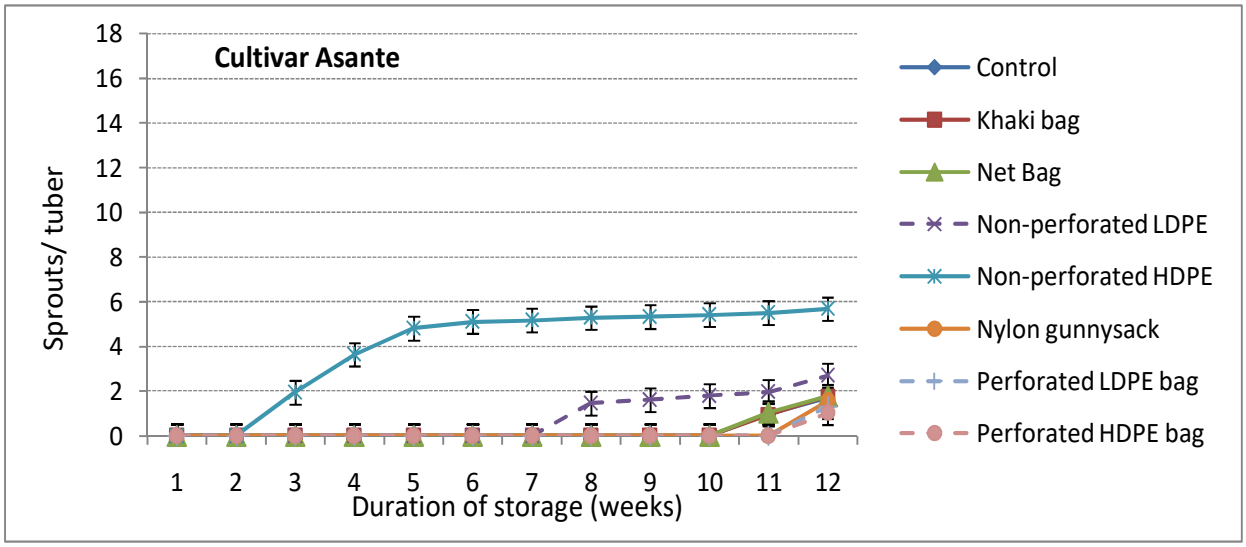
	Days to dormancy end		
	Cultivars		
Package type	Asante	Kenya Mpya	Shangi
Control (Trays)	78.33^{abc}	70.33^{cd}	40^{f}
Khaki bag	75.33^{abcd}	72^{bcd}	40^{f}
Net Bag	74.67^{abcd}	72^{bcd}	36^{fg}
Non-perforated black LDPE bag	56^{e}	66.33^{de}	28^{gh}
Non-perforated clear HDPE bag	17^{hi}	19^{hi}	10^{i}
Nylon gunnysack	77.33^{abcd}	82^{ab}	35^{fg}
Perforated black LDPE bag	78.67^{abc}	84^{a}	36^{fg}
Perforated clear HDPE bag	84^{a}	83.67^{a}	33^{fg}

Different letters in each character indicate significant differences according to Tukey's protected least significant difference test (*P*=0.05)

6.4.5 Number of sprouts per tuber

Number of sprouts per tuber was found to be significantly ($P<0.05$) influenced by the main effects of package type, cultivar and duration of storage as well as all possible interactions. The highest number of sprouts per tuber was recorded in tubers packaged in non-perforated HDPE bags throughout the 12 weeks storage duration for all the cultivars (Fig. 6.2). A significant difference in the number of sprouts per tuber was observed in tubers of different cultivars packaged in non-perforated HDPE bags with Shangi tubers having the highest mean number of sprouts (16.7) and Asante having the lowest (5.7) at the end of 12 weeks storage. Kenya Mpya tubers recorded 13.11 sprouts per tuber. Tubers packaged in non-perforated LDPE bags had 7.4, 2.7 and 2.2 sprouts per tuber for cultivar Shangi, Asante and Kenya Mpya tubers respectively. There was no difference in number of sprouts per tuber among tubers packaged in nylon gunnysacks, khaki bags, net bags, perforated PE bags and trays (control) for Asante and Kenya Mpya tubers at the end of 12 weeks storage. Sprouting on tubers packaged in nylon gunnysacks, khaki bags, net bags, perforated PE bags and unpackaged (control) occurred later in storage. As a result, lower number of sprouts per tuber was recorded for these packages (Fig. 6.2). Generally, the number of sprouts increased significantly with storage duration across all the treatments. Shangi tubers recorded the highest number of sprouts compared to Asante and Kenya Mpya tubers irrespective of the type of package.





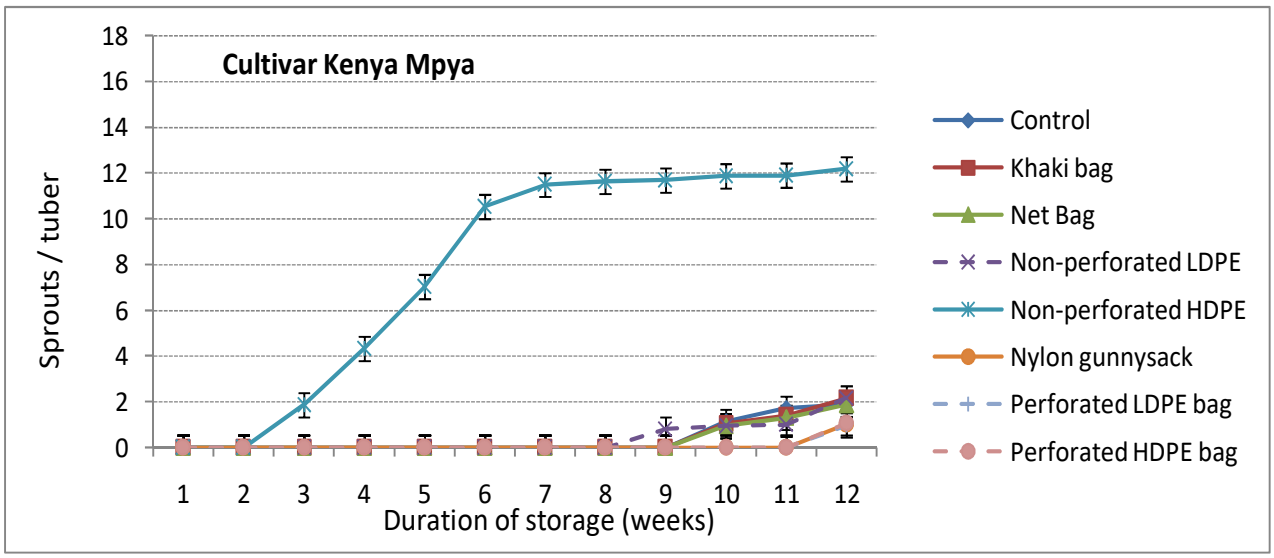


Figure 6. 2: Effect of ware potato packaging on number of sprouts per tuber during storage using three potato cultivars under ambient conditions in Kenya

6.4.6 Sprout length

The main effects of package type, cultivar and duration of storage as well as all possible interactions showed significant ($P \leq 0.05$) effect on sprout length (Appendix 5). Tubers packaged in non-perforated PE bags had longer sprouts. The longest sprout length of 15.1mm was recorded for cultivar Kenya Mpya tubers packaged in non-perforated HDPE bags at week 5 but it was reduced to 13mm at the end of 12^{th} week due to sprout apical meristem necrosis (Figure 6.3). Similarly, cultivar Shangi tubers had attained a sprout length of 14.9mm at week 4 but it had reduced to 13.4mm at the end of 12 weeks storage. In all the packages tested, cultivar Shangi tubers gave significantly high sprout length compared to Asante and Kenya Mpya tubers. Probably due to early sprouting, cultivar Shangi tubers maintained high sprout length within every package tested compared to cultivar Asante and Kenya Mpya tubers in similar package type. On the other hand, cultivar Asante tubers recorded shorter sprouts in most of the packages tested compared to Kenya Mpya tubers. Generally, sprout length increased with progress in storage period, irrespective of the packaging material (Figure 6.3). Sprout growth was more rapid in tubers packaged in non-perforated PE bags than the rest of packages in all the cultivars. Sprouting started earlier in the experiment for tubers packaged in non perforated HDPE bags across all the cultivars and consequently these treatments maintained the highest sprout length almost throughout storage. Sprouting for tubers packaged in perforated PE bags, nylon gunnysacks, khaki bags, net bags and trays (control) occurred later in storage. As a result, lengths of sprouts were limited by late sprouting observed in these packages as compared to non-perforated PE bags.

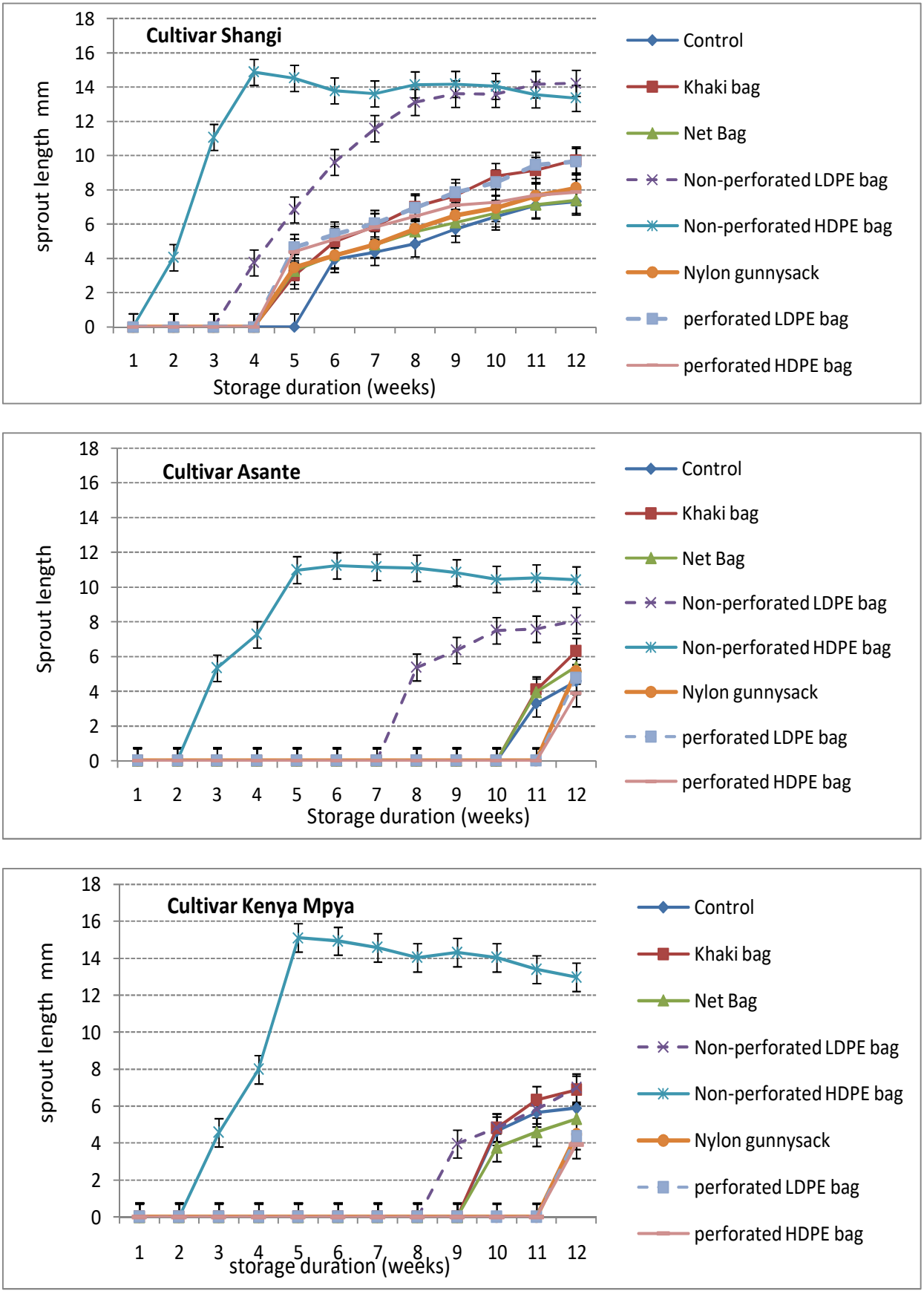
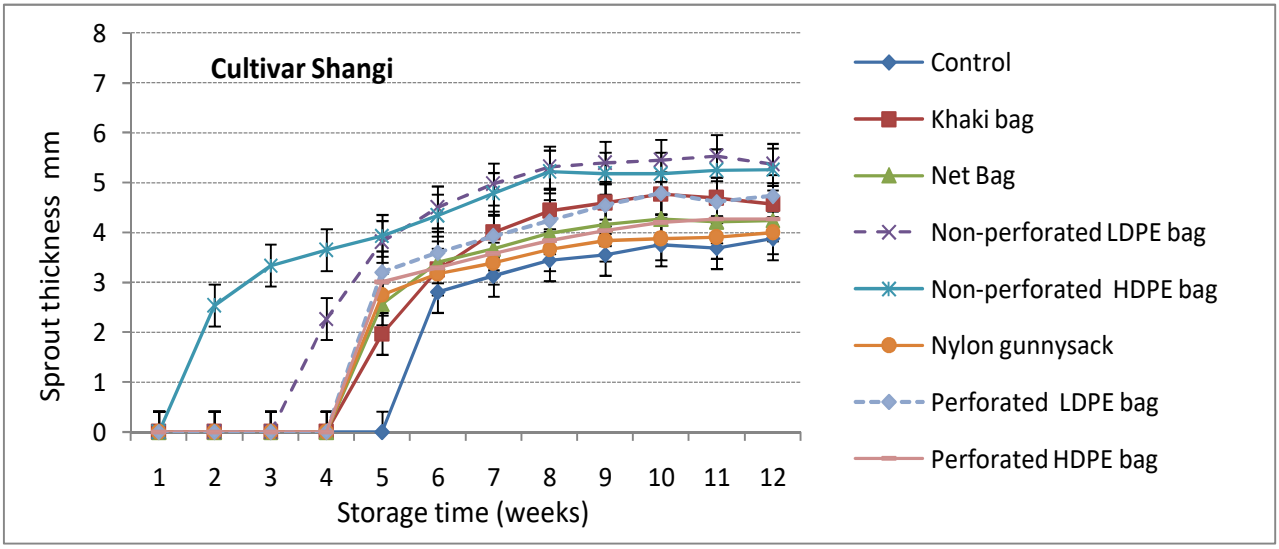
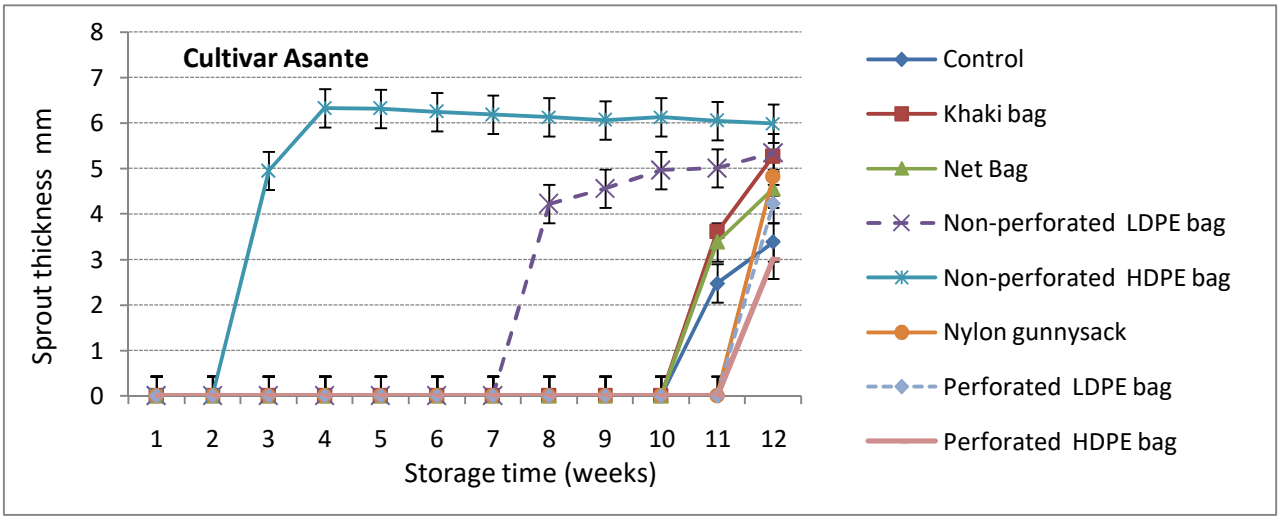


Figure 6. 3: Effect of packaging on sprout length of ware potato tubers of cultivars Shangi, Asante and Kenya Mpya during storage for 12 weeks under ambient storage.

6.4.7 Sprout thickness

The main effects due to packaging, cultivar and duration of storage as well as all the interactions significantly ($P \leq 0.05$) influenced sprout thickness (Appendix 4). Tubers packaged in non-perforated HDPE bags had thicker sprouts in all the cultivars compared to the rest of the packages. Generally, cultivar Kenya Mpya tubers produced thinner sprouts in all the packages compared to Shangi and Asante tubers. On the other hand, tubers of cultivar Asante produced thicker sprouts in most of the packages. Sprout thickness increased with storage duration (Figure 6.4).





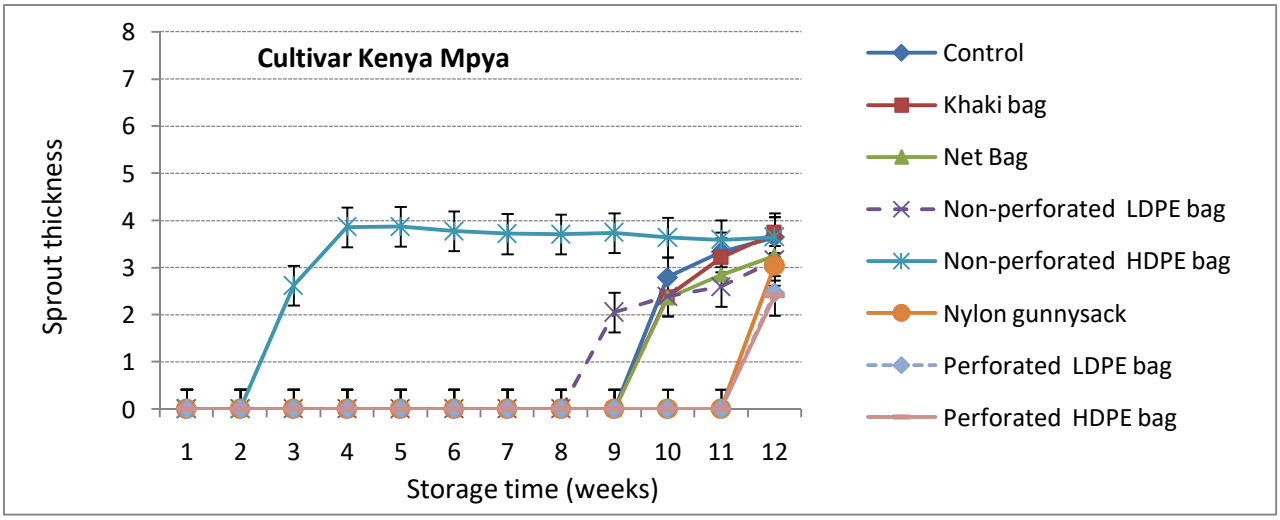


Figure 6. 4: Effect of packaging on sprout thickness of ware potato tubers of cultivars Shangi, Asante and Kenya Mpya during storage for 12 weeks under ambient storage.

6.5 DISCUSSION

The greatest losses in terms of tuber sprouting and decay occurred in tubers packaged in non-perforated polyethylene bags while the non-packaged tubers had the greatest losses in terms of weight loss, loss of tuber firmness and tuber greening. Most of the weight loss can be attributed to water loss.

Weight loss

The postharvest moisture content of vegetables is considered one of the most important factors in maintaining their quality and shelf life. Post harvest weight loss brought about by water loss is a primary factor limiting postharvest longevity in most of the vegetables. The acceptable weight loss in potato tubers is up to 10% since no visible shriveling takes place at this point (Mehta and Ezekiel, 2010). In this study, non-packaged tubers as well as tubers packaged in net bags lost the most weight of more than 10% during 32 days of storage. The tubers were shriveled hence the market value of these potatoes was greatly reduced.

Weight loss in stored tubers has been attributed to processes such as evaporation, respiration and sprouting but the main contributing factor is evaporation (Mehta et al., 2010). Sprouting results in notably large increase in weight loss due to increased moisture evaporation resulting from sprout growth (Singh and Ezekiel, 2003). Contrary to literature, the results of this study found that the highest sprouting rate, high sprout length and high number of sprouts did not result in increased weight loss. This was due to packaging of tubers especially in non-perforated PE bags. The remarkable reduction in weight loss observed in non-perforated PE bags is linked to a high relative humidity created within the package as well as limited permeability of the PE bags. The moisture evaporating from the tubers and sprouts condensed creating a high in-pack relative humidity. Several studies have reported that film packaging maintains a high relative humidity and reduces water loss (Chandran, 2009; Rodov et al., 1995; Ben-Yehoshua et al., 1983). Additionally, high relative humidity has been reported to reduce transpiration from the produce thereby reducing weight loss, wilting, shriveling and loss of firmness (Aharoni et al., 2007). Although the tubers packaged in non-perforated PE bags had multiple sprouts, they appeared firmer than the non-packaged tubers that had few sprouts. High weight loss in the non-packaged and tubers in net bags could be attributed to the high airflow rate around the tubers as observed in other studies (Whitelock et al., 1994).

Generally, permeability of packaging material to moisture loss played a great role in weight loss. The more permeable a material was, the more weight was lost. The differences observed among cultivars could be due to their genotypic differences attributed to their sprouting characteristics, skin surface and the tuber dry matter content. Cultivar Asante has high dry matter content compared to Shangi and Kenya Mpya (NPCK, 2015). Additionally, the differences in weight loss among cultivars could result from differences in skin surface permeability brought about by cuticle thickness (Lownds et al., 1993). Gachango et al. (2008) attributed weight loss among genotypes to differences in skin surface and the dry matter content of the tubers. Ezekiel et al. (2002) reported that tuber weight loss differs by cultivars, storage conditions and storage durations among other factors.

Tuber greening

Greening affects quality and palatability of potatoes. In this study, packaging the tubers reduced the rate at which greening occurred probably due to low light transmission. The lowest greened tubers were recorded in tubers packaged in non- perforated black package which had very low light transmission. The highest greening occurred in trays and net bags which had high light transmission. Khaki bags, nylon gunnysack, perforated PE bags allowed some light transmission resulting in greening. Greening was higher in packaging material with high light transmission than in packaging material with low light transmission. Rosenfeld et al. (1995) reported that greening of potato tubers packaged in different bags was proportional to the amount of light allowed in. Additionally, Rosenfeld et al. (1995) observed differences on glycoalkaloid levels in potato tubers packaged in materials with different light transmission. Cultivar differences in greening were observed. The tendency to green was low in cultivar Asante tubers. Cultivar Kenya Mpya tubers were more susceptible to tuber greening than cultivar Shangi and Asante. Varietal differences in the degree of greening of tubers exposed to light have been reported (Percival, 1999). Reeves (1988) evaluated 144 varieties and fond that greening was less in russetted varieties compared to white varieties. This is probably the reason why cultivar Kenya Mpya which has cream-white skin color showed faster and greater degree of tuber greening. On the other hand, cultivar Asante has a pink skin color and it recorded the least rate of tuber greening. Differences in potato greening among cultivars exposed to light have been reported to be an inherited genetic factor (Jakuczun and Zimnoch-Guzowska, 2006; Salunkhe and Salunkhe, 1973).

Decay incidences

Decay was heavy in non-perforated HDPE bags than the rest of the packages. This may have been brought about by high in-pack relative humidity. Moreover the water droplets found to have condensed on the tubers and inner film surfaces of the non-perforated PE bags could have contributed to the increased decay. In his review, Kader (2004) pointed out that having condensed moisture on commodity surface could enhance decay development more than increased relative humidity. Rodov et al. (2010) also suggested that having condensed moisture on the commodity surface inhibits gas exchange and enhances microbial growth. Accumulation of the condensed water within the package enhances pathological growth resulting to produce decay (Aharoni et al., 2007). As much as high relative humidity is advantageous in reducing weight loss, it is known to increase disease incidence. This study concluded that high relative humidity leading to moisture condensation was primary cause to increased decay. Additionally, tuber rotting was speculated to have been caused by soft rot (*Erwinia carotovora*). There is abundant evidence on the role of storage environment on the disease incidence and it has been established clearly that tuber decay is highly favored by anaerobic conditions. De Boer and Kelman (1978) reported that under aerobic conditions, tubers that were inoculated with E. *carotovora* remained decay free despite an increase in the population of the inoculum whereas tubers under anaerobic condition developed decay symptoms. Low oxygen levels increases the rate of decay as well (De Boer and Kelman, 1978). Tuber respiration in the non-perforated packages could have depleted the oxygen supply. Due to the limited permeability of the non-perforated HDPE bags, temperature inside the pack could have been higher than the ambient temperature hence contributing to tuber rotting. Temperatures above 28 °C is said to favour the growth of the pathogens *E. carotovora* and an increase in temperature increases the magnitude of the disease (Singh et al., 2002). No tuber rotting was reported in unpackaged, net bags, perforated bags and nylon gunny sacks. This was attributed to storage conditions that were dry thus not conducive for any disease development.

Sprouting

Packaging tubers in high density non-perforated polyethylene bags resulted in premature dormancy end, highest number of sprouts per tuber, high sprout length and thicker sprouts.

This is attributable to changes within the package especially relative humidity and gas composition. The increased relative humidity coupled with increased carbon dioxide and low oxygen concentration and rises in temperature are the likely factors that contributed to the premature dormancy termination and subsequent sprouting. High relative humidity effect in shortening tuber dormancy has been reported (Shiwachi et al., 2003; Craufurd et al., 2001). High RH has been reported to enhance sprout growth and sprout thickness (Singh and Ezekiel, 2003; Ezekiel, 2014). Goodwin (1966) reported that storing potato tubers in moist conditions at the temperature range of 20-35℃ terminated the natural rest period of tubers within one week while those stored at dry conditions were dormant for seven weeks. Additionally, Burton and Wigginton (1970) reported that when potato tubers are continuously covered by a film of water, they become anaerobic within 2.5 hours at 21^{o}C and this contributes to hastened dormancy break and bacterial rot.

Atmospheric gas composition within storage has been shown to affect tuber dormancy period. Increased carbon dioxide concentration in combination of reduced oxygen to a certain concentration has also been associated with faster dormancy break, increased number of sprouts and cell elongation (Coleman and Mclnerney, 1997; Pinhero et al., 2009; Burton, 1958). Storage in gas composition of 60% carbon dioxide and 20% oxygen at temperature of 3^{o}C and 13^{o}C maintained a high sprout length throughout the experiment as compared to the control tubers stored at ambient atmosphere of 0.03% CO_2 and 20.9% O_2 (Coleman, 1998). In addition, the author reported a decrease in abscisic acid levels within the potato tubers to almost zero (<0.04) nmol ABA g^{-1} d wt tissue 7 days after treatment with 60% carbon dioxide and 20% oxygen while the control stored at ambient atmosphere of 0.03% CO_2 and 20.9% O_2 had 1.15 nmol ABA g^{-1} d wt tissue. Gas mixtures of 60% CO_2 and 18-20% O_2 enhanced dormancy end of three potato cultivars (Coleman and McInerney, 1997). Sprout growth is reported to be stimulated by low oxygen concentration (5%) within the storage atmosphere (Burton, 1958). In this study, high carbon dioxide concentration and low oxygen could have resulted due to product respiring and restriction of air movement out of the non-perforated polyethylene packages

High temperatures are also known to promote sprout growth. It is speculated that limited permeability within non-perforated HDPE bags could have resulted in slightly higher temperature than the surrounding ambient air. Higher temperature within the non-perforated

HDPE bag could have been as a result of metabolic heat produced which raises the temperature slightly above the environment if not transferred to the surrounding air as reported by Burton (1978). Storage of tubers in plastic sacks in Ethiopia resulted in longer sprout length and more number of sprouts per tuber due to high heat temperature in the storage system (Ayalew et al., 2014).

The differences observed in sprout length, number of sprouts per tuber and sprout thickness among cultivars is attributed to their genetic differences. Previous report indicated that, number of sprout per tuber depends on genotypic factors and storage conditions among others (Struik, 2007). Cultivar Shangi which exhibited short dormancy period gave long sprouts and also high number of sprouts in every package type compared to Asante and Kenya Mpya. A relatively significant difference between cultivars were found by Carli et al. (2012) that indicates genotypes with shorter dormancy often show a greater length of their longest sprout and more number of sprouts per tuber than tuber with long dormancy period.

6.6 CONCLUSION

In this study, non-perforated polyethylene bags were manifestly more efficacious in preventing weight loss and maintaining a fresher looking tuber. However, these non-perforated polyethylene bags reduced shelf life by promoting sprouting and tuber decay. The detrimental effect of ware potato sprouting promoted by PE packaging can be used for the benefit of the seed potato industry. This therefore could minimize the problems associated with sprouting seed potato tubers given the short duration between seasons and offers a cheap and faster alternative to potato tuber sprouting. Perforation of the PE bags reversed the negative effect (excessive sprouting and tuber decay) of non-perforated PE bags. Low density black PE bags emerged as the best method for ware potato packaging due to low sprouting, reduced weight loss, low rate of tuber greening and reduced rate of tuber decay compared to the rest of packaging materials tested.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATION

Significant progress has been made through this research in establishing the sprout suppressing effect of chlorpropham, 1,4-dimethylenaphalene, peppermint oil, ethylene and paclobutrazol for storage extension of ware potatoes. Overall, the study demonstrated that chlorpropham, 1,4-dimethylenaphalene, peppermint oil, and paclobutrazol are potent potato sprout suppressants for short and long term storage of ware potatoes in Kenya. CIPC appeared to have a more significant impact on sprout suppression than DMN, peppermint oil and paclobutrazol. It has the ability to suppress sprouting beyond 24 weeks at high ambient temperature.

The study has shown DMN to be more effective in suppressing sprouting at reduced temperature compared to higher storage temperature. Peppermint oil is applied as a vapor and its suppresing effect is dependent on the application interval employed. To be able to implement peppermint oil in large commercial storage, future studies should be focused on finding the suitable system that can ensure a continuous supply of the essential oil but also at repeated intervals to optimize sprout suppression.

Sprout suppression efficacy of chlorpropham, 1,4-dimethylenaphalene, peppermint oil, and paclobutrazol have been demonstrated through this study. It is therefore important to determine the economic feasibility of using these sprout suppressants in commercial potato storage. A market analysis will be necessary for the promising sprouting suppressants since profitability will be the key factor in determining its success on the market.

Endogenous ethylene has clearly been identified as playing an important role in potato tuber dormancy (Chapter 2). There is very limited information regarding the minimum concentration required to control sprouting. Therefore the mechanisms as well as measurements of endogenous level of ethylene necessary to effectively suppress sprouting would be of value in order to obtain better understanding of mechanisms underlying dormancy and sprouting processes.

Different concentrations of the growth regulators should be evaluated for their efficacy on sprouting when tubers are grown in tropical environment.

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APPENDICES

Appendix 1: Effect of packaging material on weight loss of ware potato tubers over time

Mean sum of squares (MSS)		
Source of variation	**DF**	**Weight loss (%)**
Type of packaging (A)	7	19.02953***
Cultivar (B)	2	0.59815***
Storage duration (C)	7	39.12244***
A x B	14	0.24152***
A x C	49	4.15132***
B x C	14	0.77732***
A x B x C	98	0.11124***
Error	382	0.01783

***= highly significant at 0.05 probability level, DF= degree of freedom

Appendix 2: Effect of packaging material on tuber greening

Mean sum of squares (MSS)		
Source of variation	**DF**	**Tuber greening (%)**
Type of packaging (A)	7	55111.66***
Cultivar (B)	2	18935.62***
Storage duration (C)	4	16728.19***
A x B	14	1851.89***
A x C	28	1226.29***
B x C	8	244.13***
A x B x C	56	259.61***
Error	359	54.60

***=highlysignificant at 0.05 probability level, DF= degree of freedom

Appendix 3: Effect of packaging material on tuber decay

		Mean sum of squares (MSS)
Source of variation	**DF**	**Decay (%)**
Type of packaging material (A)	7	4408.818***
Cultivar (B)	2	1.852ns
A x B	14	7.496ns
Error	46	9.742

*** =highly significant, ns= not significant at 0.05 probability level, DF= degree of freedom

Appendix 4: Effect of packaging material on ware potato sprouting and sprout growth

		Mean sum of squares (MSS)			
Source of variation	**DF**	**Sprouting (%)**	**Sprouts per tuber**	**Sprout length**	**Sprout thickness**
Type of packaging (A)	7	40015.05***	707.5518***	946.5117***	121.16740***
Cultivar (B)	2	151963.01***	483.3745***	1268.8363***	320.97291***
Storage duration (C)	11	68982.08***	87.8259***	382.0559***	113.27304***
A x B	14	2904.58***	51.9960***	26.2267***	14.54659***
A x C	77	1670.96***	13.3340***	24.8947***	4.22593***
B x C	22	10378.61***	12.4519***	47.3865***	17.93570***
A x B x C	154	600.41***	1.9350***	4.8049***	1.52034***
Error	574	30.37	0.1079	0.2265	0.06760

***= Highly Significant at 0.05 probability level, DF= degree of freedom

Appendix 5: Effect of packaging and cultivars on dormancy duration

		Mean sum of squares (MSS)
Source of variation	**DF**	**Dormancy period**
Type of packaging (A)	7	2701.48***
Cultivar (B)	2	10326.06***
A x B	14	194.39***
Error	46	12.52

*** = highly significant at 0.05 probability level, DF= degree of freedom

Appendix 6: Effect of post-harvest application of sprout suppressants on quality and storability of ware potato tubers during 24 weeks storage

		Means sum of squares (MSS)		
Source of variation	**DF**	**Sprouting %**	**Sprout length**	**sprouts per tuber**
Cultivar (A)	2	17055.769***	176.9577***	225.7632***
Treatment (B)	3	98238.390***	2686.4335***	910.0937***
Storage duration (C)	12	12985.897***	215.8123***	87.9206***
A x B	6	5560.613***	74.7672***	144.5147***
A x C	24	755.075***	19.1128***	9.9143***
B x C	36	2777.588***	94.4723***	38.4311***
A x B x C	72	812.079***	10.0272***	6.9061***
Error	310	9.417	0.4704	0.1260

***= highly significant at 0.05 probability level, DF= degree of freedom

Appendix 7: Effect of post-harvest treatments with sprout suppressants on weight loss of potato tubers after 24 weeks in storage

		Mean sum of squares (MSS)
Source of variation	**DF**	**Weight loss (%)**
Treatment (A)	3	122.8902***
Cultivar (B)	2	12.1547***
A x B	6	5.4989***
Error	22	0.6154

***=highly significant at 0.05 probability level, DF= degree of freedom

Appendix 8: Effect of storage temperature and sprout suppressants on quality and storability of ware potato tubers during 24 weeks storage

		Means sum of squares (MSS)		
Source of variation	**DF**	**Sprouting %**	**Sprout length**	**Sprouts/ tuber**
Storage temp (A)	1	40940***	944.2220***	348.8***
Treatment (C)	3	151000***	3221.3479***	1119***
Cultivar (B)	2	15840***	197.4265***	237.8***
Storage duration (D)	12	20920***	315.7973***	127.1***
A x C	3	6622***	282.9442***	90.51***
A x B	2	2689***	24.3258***	35.43***
B x C	6	5286***	72.5375***	153.6***
A x D	12	1371***	26.5828***	10.59***
C x D	36	5847***	159.8246***	67.80***
B x D	24	587.8***	14.0945***	8.854***
A x B x C	6	1726***	28.9083***	2.347***
A x C x D	36	1058***	13.3753***	4.067***
A x B x D	24	489***	11.5765***	4.702***
B x C x D	72	590.9***	7.6058***	6.718***
A x B x C x D	72	631.3***	8.3109***	3.970***
Error	622	8.329	0.3160	0.07142

***= highly significant at 0.05 probability level, DF= degree of freedom, temp= temperature

Appendix 9: Effect of pre-harvest treatments on dormancy period of potato tubers stored at ambient and cold store

		Mean sum of squares (MSS)	
Source of variation	**DF**	**Ambient storage**	**Cold storage**
Treatment (A)	2	1770.481***	23.259*
Cultivar (B)	2	3930.481***	2233.593***
A x B	4	25.815***	7.648ns
Error	16	2.523	4.176

***= highly significant,*= significant, ns= not significant at 0.05 probability level DF= degree of freedom

Appendix 10: Effect of pre-harvest application of growth inhibitors on storability of ware potato tubers during storage at ambient temperature

		Means sum of squares (MSS)			
Source of variation	**DF**	**Sprouting %**	**Sprout length**	**Sprouts/tuber**	**Sprout thickness**
Cultivar (A)	2	71931.91***	1233.380***	252.2106***	166.7833***
Treatment (B)	2	20459.26***	470.356***	74.1487***	49.8608***
Storage duration (C)	12	32373.36***	412.523***	68.3508***	87.1732***
A x B	4	765.24***	54.068***	18.2223***	3.7149***
A x C	24	3579.13***	43.992***	8.4814***	6.2778***
B x C	24	847.22***	15.250***	3.8761***	2.2939***
A x B x C	48	1539.32***	11.541***	0.7135***	1.5744***
Error	232	34.16	1.652	0.1458	0.1026

****=highly significant at 0.05 probability level, DF= degree of freedom

Appendix 11: Effect of pre-harvest application of growth inhibitors on storability of ware potato tubers during storage at low temperature

		Means sum of squares (MSS)			
Source of variation	**DF**	**Sprouting %**	**Sprout length**	**Sprouts per tuber**	**Sprout thickness**
Treatment (B)	2	46.91*	33.0185***	4.9335***	0.00483ns
Cultivar (A)	2	29024.07***	530.7056***	190.6302***	42.34437***
Storage duration (C)	17	27189.22***	318.2392***	71.0264***	34.58261***
A x B	4	29.32ns	7.4909***	1.6638***	0.14845***
B x C	34	15.98ns	6.8639***	0.8827***	0.02478ns
A x C	34	4657.19***	76.6251***	22.5768***	8.06075***
A x B x C	68	16.03ns	2.0195***	0.3084***	0.03561ns
Error	322	13.43	0.6940	0.1013	0.02676

***=highly significant, *=significant, ns= not significant at 0.05 probability level, DF= degree of freedom

Appendix 12: Effect of pre-harvest treatments on weight loss of potato tubers at ambient and cold storage

		Mean sum of squares (MSS)	
Source of variation	**DF**	**Ambient storage**	**Cold storage**
Treatment (A)	2	2.75977***	0.08144ns
Cultivar (B)	2	10.59978***	2.23805***
A x B	4	0.17637ns	0.00822ns
Error	16	0.06710	0.02308

***= highly significant, ns=not significant at 0.05 probability level, DF= degree of freedom